UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE

REPORT DOCUMENTATION PAGE

1a. REPORT SECURITY CLASSIFICATION UNCLASSIFIED	1b. RESTRICTIVE MARKINGS
2a. SECURITY CLASSIFICATION AUTHORITY	3. DISTRIBUTION / AVAILABILITY OF REPORT Approved for public release; distribution is unlimited
2b. DECLASSIFICATION / DOWNGRADING SCHEDULE	
4. PERFORMING ORGANIZATION REPORT NUMBER(S) CR 87-16	5. MONITORING ORGANIZATION REPORT NUMBER(S) CR 87-16
6a. NAME OF PERFORMING ORGANIZATION Science Applications International Corp. 6b. OFFICE SYMBOL (If applicable)	7a. NAME OF MONITORING ORGANIZATION Naval Environmental Prediction Research Facility
6c. ADDRESS (City, State, and ZIP Code) 205 Montecito Avenue Monterey, CA 93940	7b. ADDRESS (City, State, and ZIP Code) Monterey, CA 93943-5006
8a. NAME OF FUNDING / SPONSORING ORGANIZATION Commander, Naval Oceanography Command 8b. OFFICE SYMBOL (If applicable)	9. PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER N00228-84-D-3187
8c. ADDRESS (City, State, and ZIP Code) NSTL, MS 39529-5000	10. SOURCE OF FUNDING NUMBERS PROGRAM ELEMENT NO. / PROJECT NO. / TASK NO. / WORK UNIT ACCESSION NO. DN656794

11. TITLE (Include Security Classification)

Severe Weather Guide - Mediterranean Ports - 10. Malaga (U)

12. PERSONAL AUTHOR(S)

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13a. TYPE OF REPORT	13b. TIME COVERED	14. DATE OF REPORT (Year, Month, Day)	15. PAGE COUNT
Final	FROM 9/13/84 TO 6/1/87	1988, March	69

16. SUPPLEMENTARY NOTATION

Funding source: O & M, N-1

17. COSATI CODES			18. SUBJECT TERMS (Continue on reverse if necessary and identify by block number)
FIELD	GROUP	SUB-GROUP	
04	02		Storm haven; Malaga port; Mediterranean meteorology; Mediterranean oceanography

19. ABSTRACT (Continue on reverse if necessary and identify by block number)

This handbook for the port of Malaga, one in a series of severe weather guides for Mediterranean ports, provides decision-making guidance for ship captains whose vessels are threatened by actual or forecast strong winds, high seas, restricted visibility or thunderstorms in the port vicinity. Causes and effects of such hazardous conditions are discussed. Precautionary or evasive actions are suggested for various vessel situations. The handbook is organized in four sections for ready reference: general guidance on handbook content and use; a quick-look captain's summary; a more detailed review of general information on environmental conditions; and an appendix that provides oceanographic information.

20. DISTRIBUTION / AVAILABILITY OF ABSTRACT ☒ UNCLASSIFIED/UNLIMITED ☐ SAME AS RPT. ☐ DTIC USERS	21. ABSTRACT SECURITY CLASSIFICATION UNCLASSIFIED	
22a. NAME OF RESPONSIBLE INDIVIDUAL Perryman, Dennis C., contract monitor	22b. TELEPHONE (Include Area Code) (408) 647-4709	22c. OFFICE SYMBOL O&M,N-1

DD FORM 1473, 84 MAR — 83 APR edition may be used until exhausted. All other editions are obsolete.

SECURITY CLASSIFICATION OF THIS PAGE

UNCLASSIFIED

AN (1) AD-A199 669
FG (2) 040200
CI (3) (U)
CA (5) SCIENCE APPLICATIONS INTERNATIONAL CORP MONTEREY CA
TI (6) Severe weather Guide - Mediterranean Ports. 10. Malaga.
TC (8) (U)
DN (9) Final rept. 13 Sep 84-1 Jun 87,
AU (10) Englebretson, Ronald E.
AU (10) Gilmore, Richard D.
RD (11) Mar 1988
PG (12) 72p
CT (15) N00228-84-D-3187
RN (18) NEPRF-CR-87-16
RC (20) Unclassified report
NO (21) See also Number 11, AD-A199 670.
DE (23) *WEATHER, *PORTS, (FACILITIES), HANDBOOKS, HAZARDS, ADVERSE CONDITIONS, MEDITERRANEAN SEA, OCEANOGRAPHIC DATA, THUNDERSTORMS, OCEAN WAVES, VISIBILITY, WIND, SHIPS, OPERATION, SPAIN.
DC (24) (U)
ID (25) WUDN656794, Malaga(Spain), *Severe weather.
IC (26) (U)
AB (27) This handbook for the port of malaga, one in a series of severe weather guides for Mediterranean ports, provides decision-making guidance for ship captains whose vessels are threatened by actual or forecast strong winds, high seas, restricted visibility or thunderstorms in the port vicinity. Causes and effects of such hazardous conditions are discussed. Precautionary or evasive actions are suggested for various vessel situations. The handbook is organized in four sections for ready reference: general guidance on handbook content and use; a quick-look captain's summary; a more detailed review of general information on environmental conditions; and an appendix that provides oceanographic information. (FR)
AC (28) (U)
DL (33) 01
SE (34) F
CC (35) 417277

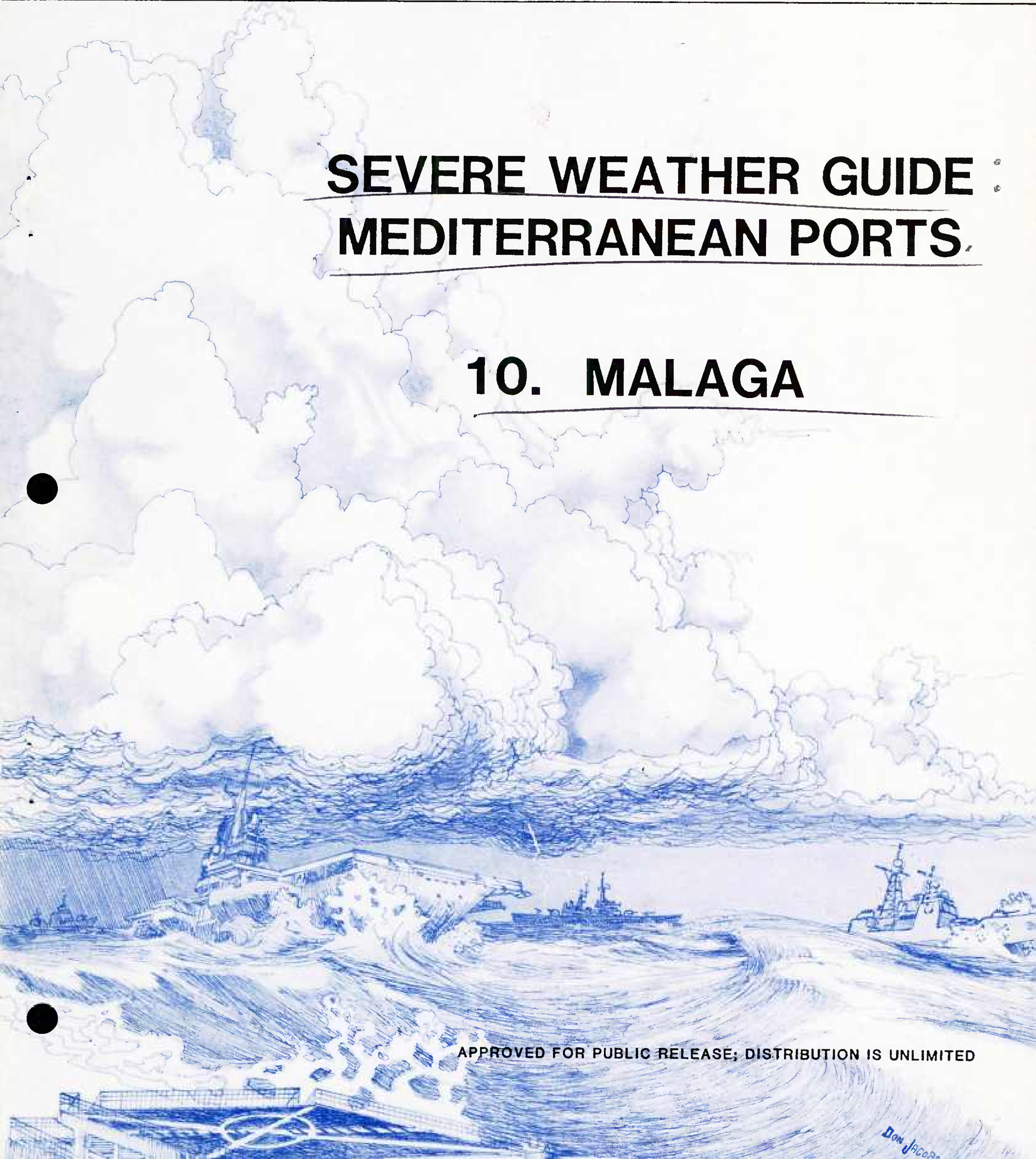
#

Naval Environmental Prediction Research Facility
Monterey, CA 93943-5006

Contractor Report CR 87-16 March 1988

SEVERE WEATHER GUIDE MEDITERRANEAN PORTS

10. MALAGA



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CONTENTS

FOREWORD

This handbook on Mediterranean Ports was developed as part of an ongoing effort at the Naval Environmental Prediction Research Facility to create products for direct application to Fleet operations. The research was conducted in response to Commander Naval Oceanography Command (CNOC) requirements validated by the Chief of Naval Operations (CNO).

As mentioned in the preface, the Mediterranean region is unique in that several areas exist where local winds can cause dangerous operating conditions. This handbook will provide the ship's captain with assistance in making decisions regarding the disposition of his ship when heavy winds and seas are encountered or forecast at various port locations.

Readers are urged to submit comments, suggestions for changes, deletions and/or additions to NOCC, Rota with a copy to the oceanographer, COMSIXTHFLT. They will then be passed on to the Naval Environmental Prediction Research Facility for review and incorporation as appropriate. This document will be a dynamic one, changing and improving as more and better information is obtained.

M. G. SALINAS
Commander, U.S. Navy

PORT INDEX

The following is a tentative prioritized list of Mediterranean Ports to be evaluated during the five-year period 1988-92, with ports grouped by expected year of the port study's publication. This list is subject to change as dictated by circumstances and periodic review.

1988 NO.	PORT
1	GAETA, ITALY
2	NAPLES, ITALY
3	CATANIA, ITALY
4	AUGUSTA BAY, ITALY
5	CAGLIARI, ITALY
6	LA MADDALENA, ITALY
7	MARSEILLE, FRANCE
8	TOULON, FRANCE
9	VILLEFRANCHE, FRANCE
10	MALAGA, SPAIN
11	NICE, FRANCE
12	CANNES, FRANCE
13	MONACO
14	ASHDOD, ISRAEL
15	HAIFA, ISRAEL
	BARCELONA, SPAIN
	PALMA, SPAIN
	IBIZA, SPAIN
	POLLENSA BAY, SPAIN
	VALENCIA, SPAIN
	CARTAGENA, SPAIN
	GENOA, ITALY
	LIVORNO, ITALY
	SAN REMO, ITALY
	LA SPEZIA, ITALY
	VENICE, ITALY
	TRIESTE, ITALY

1989	PORT
	SPLIT, YUGOSLAVIA
	DUBROVNIK, YUGOSLAVIA
	TARANTO, ITALY
	PALERMO, ITALY
	MESSINA, ITALY
	TAORMINA, ITALY
	PORTO TORRES, ITALY

1990	PORT
	BENIDORM, SPAIN
	ROTA, SPAIN
	TANGIER, MOROCCO
	PORT SAID, EGYPT
	ALEXANDRIA, EGYPT
	ALGIERS, ALGERIA
	TUNIS, TUNISIA
	GULF HAMMAMET, TUNISIA
	GULF OF GABES, TUNISIA
	SOUDA BAY, CRETE

1991	PORT
	PIRAEUS, GREECE
	KALAMATA, GREECE
	THESSALONIKI, GREECE
	CORFU, GREECE
	KITHIRA, GREECE
	VALETTA, MALTA
	LARNACA, CYPRUS

1992	PORT
	ANTALYA, TURKEY
	ISKENDERUN, TURKEY
	IZMIR, TURKEY
	ISTANBUL, TURKEY
	GOLCUK, TURKEY
	GULF OF SOLLUM

PREFACE

Environmental phenomena such as strong winds, high waves, restrictions to visibility and thunderstorms can be hazardous to critical Fleet operations. The cause and effect of several of these phenomena are unique to the Mediterranean region and some prior knowledge of their characteristics would be helpful to ship's captains. The intent of this publication is to provide guidance to the captains for assistance in decision making.

The Mediterranean Sea region is an area where complicated topographical features influence weather patterns. Katabatic winds will flow through restricted mountain gaps or valleys and, as a result of the venturi effect, strengthen to storm intensity in a short period of time. As these winds exit and flow over port regions and coastal areas, anchored ships with large 'sail areas' may be blown aground. Also, hazardous sea state conditions are created, posing a danger for small boats ferrying personnel to and from port. At the same time, adjacent areas may be relatively calm. A glance at current weather charts may not always reveal the causes for these local effects which vary drastically from point to point.

Because of the irregular coast line and numerous islands in the Mediterranean, swell can be refracted around such barriers and come from directions which vary greatly with the wind. Anchored ships may experience winds and seas from one direction and swell from a different direction. These conditions can be extremely hazardous for tendered vessels. Moderate to heavy swell may also propagate outward in advance of a storm resulting in uncomfortable and sometimes dangerous conditions, especially during tending, refueling and boating operations.

This handbook addresses the various weather conditions, their local cause and effect and suggests some evasive action to be taken if necessary. Most of the major ports in the Mediterranean will be covered in the handbook. A priority list, established by the Sixth Fleet, exists for the port studies conducted and this list will be followed as closely as possible in terms of scheduling publications.

RECORD OF CHANGES

CHANGE NUMBER	DATE OF CHANGE	DATE ENTERED	PAGE NUMBER	ENTERED BY

1. GENERAL GUIDANCE

1.1 DESIGN

This handbook is designed to provide ship captains with a ready reference on hazardous weather and wave conditions in selected Mediterranean harbors. Section 2, the captain's summary, is an abbreviated version of section 3, the general information section intended for staff planners and meteorologists. Once section 3 has been read, it is not necessary to read section 2.

1.1.1 Objectives

The basic objective is to provide ship captains with a concise reference of hazards to ship activities that are caused by environmental conditions in various Mediterranean harbors, and to offer suggestions for precautionary and/or evasive actions. A secondary objective is to provide adequate background information on such hazards so that operational forecasters, or other interested parties, can quickly gain the local knowledge that is necessary to ensure high quality forecasts.

1.1.2 Approach

Information on harbor conditions and hazards was accumulated in the following manner:

A. A literature search for reference material was performed.

B. Cruise reports were reviewed.

C. Navy personnel with current or previous area experience were interviewed.

D. A preliminary report was developed which included questions on various local conditions in specific harbors.

E. Port/harbor visits were made by NEPRF personnel; considerable information was obtained through interviews with local pilots, tug masters, etc; and local reference material was obtained (See section 3 references).

F. The cumulative information was reviewed, combined, and condensed for harbor studies.

1.1.3 Organization

The Handbook contains two sections for each harbor. The first section summarizes harbor conditions and is intended for use as a quick reference by ship captains, navigators, inport/at sea OOD's, and other interested personnel. This section contains:

A. a brief narrative summary of environmental hazards,

B. a table display of vessel location/situation, potential environmental hazard, effect-precautionary/evasion actions, and advance indicators of potential environmental hazards,

C. local wind wave conditions, and

D. tables depicting the wave conditions resulting from propagation of deep water swell into the harbor.

The swell propagation information includes percent occurrence, average duration, and the period of maximum wave energy within height ranges of greater than 3.3 feet and greater than 6.6 feet. The details on the generation of sea and swell information are provided in Appendix A.

The second section contains additional details and background information on seasonal hazardous conditions. This section is directed to personnel who have a need for additional insights on environmental hazards and related weather events.

1.2. CONTENTS OF SPECIFIC HARBOR STUDIES

This handbook specifically addresses potential wind and wave related hazards to ships operating in various Mediterranean ports utilized by the U.S. Navy. It does not contain general purpose climatology and/or comprehensive forecast rules for weather conditions of a more benign nature.

The contents are intended for use in both pre-visit planning and in situ problem solving by either mariners or environmentalists. Potential hazards related to both weather and waves are addressed. The oceanographic information includes some rather unique information relating to deep water swell propagating into harbor shallow water areas.

Emphasis is placed on the hazards related to wind, wind waves, and the propagation of deep water swell into the harbor areas. Various vessel locations/situations are considered, including moored, nesting, anchored, arriving/departing, and small boat operations. The potential problems and suggested pre-cautionary/evasive actions for various combinations of environmental threats and vessel location/situation are provided. Local indicators of environmental hazards and possible evasion techniques are summarized for various scenarios.

CAUTIONARY NOTE: In September 1985 Hurricane Gloria raked the Norfolk, VA area while several US Navy ships were anchored on the muddy bottom of Chesapeake Bay. One important fact was revealed during this incident: Most all ships frigate size and larger dragged anchor, some more than others, in winds of over 50 knots. As winds and waves increased, ships 'fell into' the wave troughs, BROADSIDE TO THE WIND and become difficult or impossible to control.

This was a rare instance in which several ships of recent design were exposed to the same storm and much effort was put into the documentation of lessons learned. Chief among these was the suggestion to evade at sea rather than remain anchored at port whenever winds of such intensity were forecast.

2. CAPTAIN'S SUMMARY

The Port of Malaga, Spain is located about 65 mi northeast of Gibralter on the north shore of the Alboran Sea (see Figure 2-1).

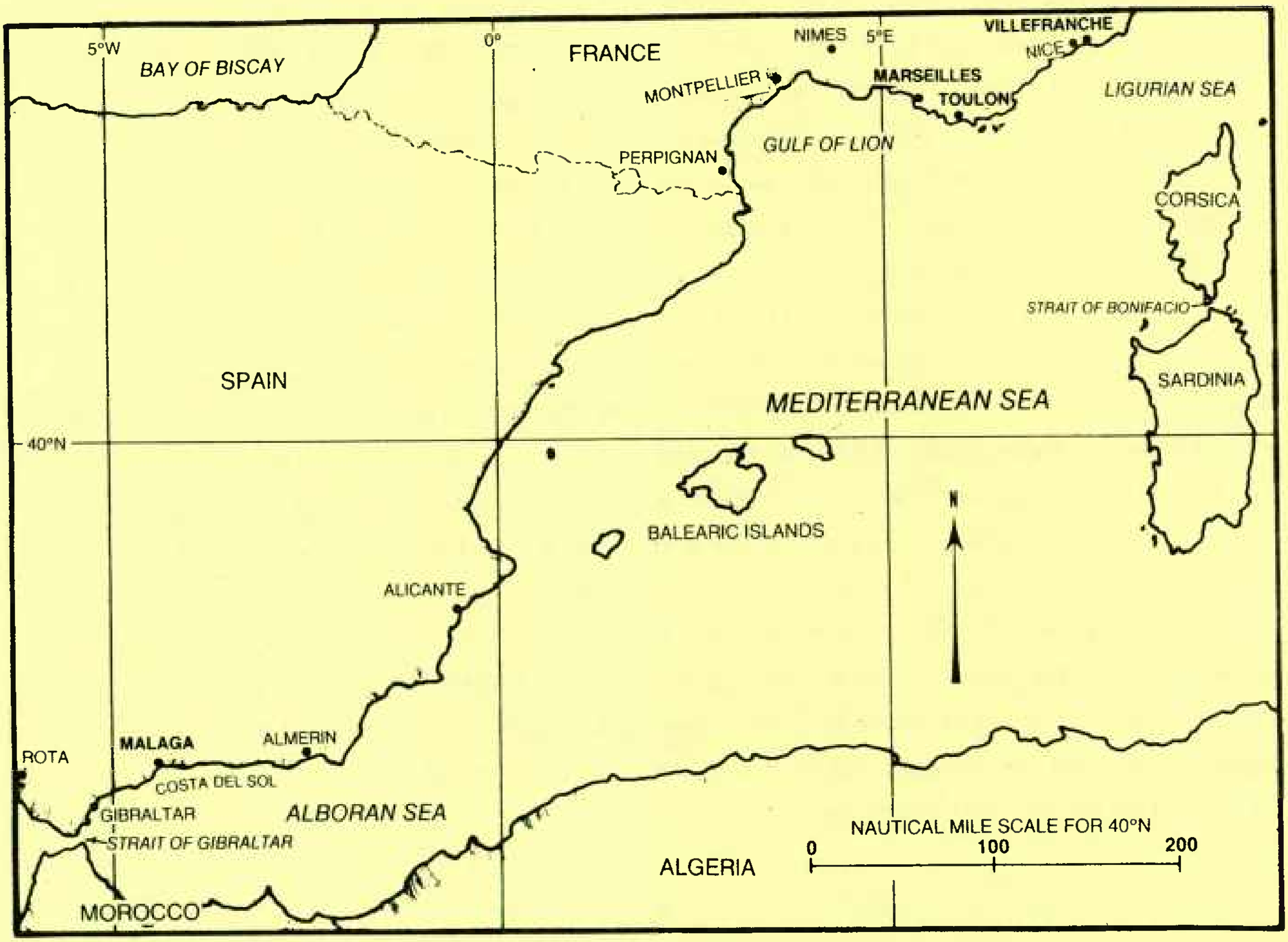

Figure 2-1. Western Mediterranean Sea.

The Port of Malaga, except for it's three inner harbors, is exposed and vulnerable to waves generated by the three most common, large-scale wind regimes: the southeasterly Levante, southwesterly Vendaval, and west to northwest Poniente. The entire Port is exposed to Levante and Vendaval winds, although the effect on Port operations is less than that imposed by the waves.

The harbor is protected on the west and north by the coast of Spain (Figure 2-2). A short promontory of land protects the east side of Guadiaro and Heredia Inner Harbors. Breakwaters have been constructed to protect the third inner harbor and the east and south sides of the outer harbor. The east breakwater, however, provides only limited protection to the outer harbor from waves produced by Levante (southeasterly) winds which create the worst conditions at the Port. Waves tend to refract around the south end of the breakwater and move northeastward through the harbor entrance and cause hazardous motion of vessels moored to the large grain pier located on the west side of the breakwater. Northeast moving swell waves generated by Vendaval (southwesterly) also pass through the harbor entrance and affect harbor operations.

The anchorage, which is located about 0.5 to 1 n mi east of the south end of the east breakwater, is exposed to wind and waves. The bottom is mostly mud with some sand and provides good holding even in high wind and wave conditions (FICEURLANT, 1985).

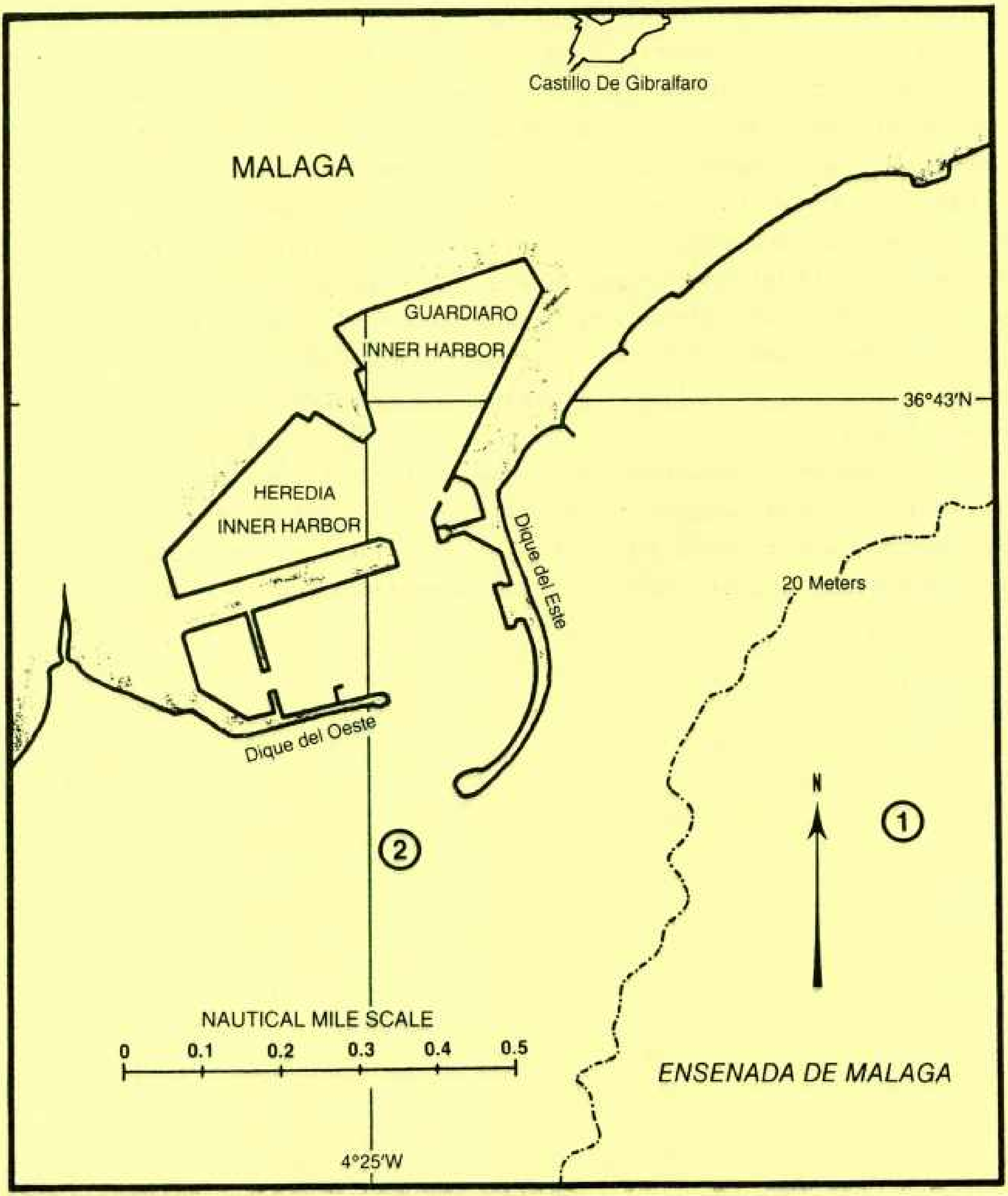

Figure 2-2. Port of Malaga.

The normal tidal range at the Port is about 2 ft (60 cm), but an easterly wind can raise the water level in the harbor. There is a persistent current with a southwest set near the entrance to the harbor. A 2 kt velocity is common, but 3 kt has been observed in the vicinity of the west breakwater. According to Hydrographic Department (1963), wind direction, sea state, and tidal conditions exert considerable influence on the rate and direction of the current. West moving currents have been observed along the coast while a current moving in the opposite direction was observed about 3 n mi offshore.

Specific hazardous atmospheric conditions, vessel situations, and suggested precautionary/evasion action scenarios are summarized in Table 2-1. Hazards for both in the harbor and at anchorage are addressed.

Table 2-1. Summary of hazardous environmental conditions for the Port of Malaga, Spain.

HAZARDOUS CONDITION	INDICATORS OF POTENTIAL HAZARD	VESSEL LOCATION/ SITUATION AFFECTED	EFFECT - PRECAUTIONARY/EVASIVE ACTIONS
1. Levante winds/waves - E to SE'ly winds create Port's worst conditions. * Force 8 (34-40 kt) winds possible. * Waves may reach 10-13 ft (3-4 m). * Strongest conditions occur in late autumn, winter, early spring, but Levante events occur year-round.	Advance warning. * If Levante winds exist in the Strait of Gibraltar, SE'ly swell will reach Malaga 24 hrs after onset in the Strait. * Levante conditions are sometimes preceded by a non-tidal water rise in Malaga harbor. * Mistral conditions in the Gulf of Lion often precede Levante conditions at Malaga. Intensity. * Winds of force 8 (34-40 kt) with 10-13 ft (3-4 m) waves can be expected 2-3 times/year at Malaga. Duration. * Strong events (wind of force 8 (34-40 kt) may last 3-4 days. Weaker events are shorter lived. Associated weather. * Summer Levantes are accompanied by good weather and haze. * Autumn/winter/spring Levantes bring low clouds, heavy rain, and reduced visibility.	(1) Moored - inner harbor.	(a) Minimal effect. * Additional mooring lines may be required to reduce vessel movement in strong winds. * Minimize personnel exposure on weather decks during strong event.
		(2) Moored - outer harbor.	(a) Waves create hazardous conditions at grain pier on W side of E breakwater. * E to SE'ly waves refract clockwise around S end of E breakwater into outer harbor. * NE'ly moving refracted waves impact vessels moored to the grain pier while E to SE'ly winds exert forces in opposite direction, resulting in rolling motion that is hazardous to ship, camels, and pier. * Evasion at sea is recommended. (b) Conditions may make outside activities unsafe. * Minimize personnel exposure on weather decks.
		(3) Anchored.	(a) Wind/waves impact the anchorage with full open-ocean force. * Good holding in high winds/waves on a mud and sand bottom should preclude need to leave the anchorage in all but strongest events. * Deployment of second anchor may be required. * If conditions dictate leaving the anchorage, nearby ports will be no better. * To gain protection from E to SE winds/seas, vessels will need to go to more protected areas west of the Strait of Gibraltar or move to NE in Mediterranean Sea until winds/waves abate. * Conditions will likely be worse in Strait of Gibraltar. * Ports on W coast of Spain (Rota, for example) may provide reduced waves but wind effects may be the same as Malaga or stronger due to terrain effects. (b) Conditions may make outside activities unsafe. * Minimize personnel exposure on weather decks.
		(4) Arriving/departing.	(a) Wind/waves may make the harbors and anchorage hazardous. * Inbound vessels should delay arrival until after conditions abate. * Outbound vessels should accelerate departure to avoid worst conditions. (b) Winds may make vessel handling difficult at slow SOA. (c) Pilot boats will not leave harbor when winds reach force 6 (22-27 kt).
		(5) Small boats.	(a) Small boat operation is curtailed under high wind/wave conditions. * Boats will not be operated in waves exceeding 3 ft (1 m). * Winds of 12 kt or greater rapidly raise waves exceeding small craft limits. * Boats will not leave harbor if winds reach force 6 (22-27 kt).
2. Vendaval winds/waves - SW'ly winds and waves precede cold frontal passage. * Force 8 (34-40 kt) winds possible. * Waves of 6 ft (2 m) or higher possible in Port area. * Most common from November through April.	Advance warning. * Cold front approaching Strait of Gibraltar while Levante conditions exist at Malaga during November-April period. Duration. * Will likely persist until frontal system passes Malaga or dissipates west of Malaga. Associated weather. * Onset of precipitation may be delayed for 6-12 hr after Vendaval onset. * Associated precipitation is usually of the non-convective type.	(1) Moored - inner harbor.	(a) Minimal effect. * SW'ly wind/swell may cause vessel movement in inner harbor, but additional mooring lines should minimize excess movement. * Wind may make outside activities unsafe. Minimize personnel exposure on weather decks.
		(2) Moored - outer harbor.	(a) Hazardous vessel movement possible if moored on W side of E breakwater. * Additional mooring lines may be required to minimize excessive vessel movement. * Strong conditions may dictate leaving the harbor. No nearby havens available. (b) Wind may make outside activities unsafe. * Minimize personnel exposure on weather decks.
		(3) Anchored.	(a) Minimal effect. * Good holding afforded by mud and sand bottom should allow ships to remain in anchorage. * Two anchors may be required if high swell is forecast. * Conditions may make outside activities unsafe. Minimize personnel exposure on weather decks.
		(4) Arriving/departing.	(a) Minimal effects. * Winds may make vessel handling difficult at slow SOA. * Pilot boats will not leave harbor when winds reach force 6 (22-27 kt). * Inbound/outbound units should schedule arrival/departure to avoid worst conditions.
		(5) Small boats.	(a) Small boat operation is curtailed under high wind/wave conditions. * Boats will not be operated in waves exceeding 3 ft (1 m). * Winds of 12 kt or greater rapidly raise waves exceeding small craft limits. * Boats will not leave harbor if winds reach force 6 (22-27 kt).

Table 2-1. (Continued)

HAZARDOUS CONDITION	INDICATORS OF POTENTIAL HAZARD	VESSEL LOCATION/ SITUATION AFFECTED	EFFECT - PRECAUTIONARY/EVASIVE ACTIONS
3. Poniente winds/waves - W to NW'ly winds follow cold frontal passage. * Due to lee trough along coast, wind force at Malaga is light. * Swell waves of 6 ft (2 m) reach Port area. * Most common from November through April.	Advance warning. * Strongest winds normally follow passage of upper level trough through the area. * Lee trough reduces wind force along coast but stronger winds offshore generate swell waves which propagate to Malaga. Duration. * Swell waves will persist until offshore winds subside. Associated weather. * Mostly clear skies prevail, but a few cumulus clouds with occasional rain showers may be observed. * When occurring, showers are most common over land from 1500Z-2000Z and over water from 2200Z-1000Z.	(1) Moored - inner harbor.	(a) Minimal effect. * SW'ly swell may cause vessel movement in inner harbor, but additional mooring lines should minimize excess movement.
		(2) Moored - outer harbor.	(a) Hazardous vessel movement possible from wave motion if moored on W side of E breakwater. * Additional mooring lines may be required to minimize excessive vessel movement. * High waves may dictate leaving the harbor. No nearby havens available.
		(3) Anchored.	(a) Minimal problems expected due to lack of wind, relatively low wave heights, and good holding on a mud and sand bottom.
		(4) Arriving/departing.	(a) Minimal problems expected in the Port for inbound/outbound units. * Pilot boats will not leave harbor if winds reach force 6 (22-27 kt). * Outbound units should anticipate increased winds/waves if track takes them south of lee trough along coast.
		(5) Small boats.	(a) Small boat operation is curtailed under high wind/wave conditions. * Boats will not be operated in waves exceeding 3 ft (1 m). * Winds of 12 kt or greater rapidly raise waves exceeding small craft limits. * Boats will not leave harbor if winds reach force 6 (22-27 kt).
4. Terra winds - N'ly winds. * Raise a chop in Port that impacts small boat operations. * Most likely to occur from November through April.	Advance warning. * Most likely in November - April period when cold, high pressure is invading the Iberian Peninsula. * Surface pressure about 200 n mi NW or N of Malaga of 7 mb or more higher than Malaga will produce N'ly winds of 20+ kt in the harbor.	(1) Small boats.	(a) Small boat operation is curtailed under high wind/wave conditions. * N'ly wind of 20+ kt will raise waves exceeding small craft limit of 3 ft (1 m) in some areas of the Port.
5. Sea breeze - S to SW'ly wind. * May reach force 5 (17-21 kt). * Lasts from about 1100L-1900L.	Advance warning. * Occurs during all months except December and January. * Strongest during Summer. * Most likely on warm days when no steep pressure gradient exists over Malaga area.	(1) Small boats.	(a) Sea breeze of over 12 kt can quickly raise problem waves for small boats in Port. * Safe operating limit for small boats is 3 ft (1 m).
		(2) Anchored	(a) Sea breeze direction follows the sun as surrounding hills are heated. * Direction backs from southerly through southwesterly from onset to end of sea breeze. * Single anchor allows free swing of vessels.

For estimating shallow water wave heights, two anchorage areas have been selected. Point 1 is for the outer harbor anchorage area for vessels with drafts over 30 ft. Point 2 is near the inner harbor entrance.

Table 2-2 provides the height ratio and direction of shallow water waves to expect at points 1 and 2 (Figure 2-2) when the deep water wave conditions are known. The Malaga Point 1 conditions are found by entering Table 2-2 with the forecast or known deep water wave direction and period. In the following example, the height is determined by multiplying the deep water height (8 ft) by the ratio of shallow to deep height (.9) for deep water swell from 120° with a 12 second period.

> Example: Use of Table 2-2 for Malaga Point 1 (Fleet Anchorage).
>
> Deep water wave forecast as provided by a forecast center or a reported/observed deep water wave condition:
>
> 8 feet, 12 seconds, from 120°.
>
> The expected wave condition at Malaga Point 1, as determined from Table 2-2:
>
> 7 feet, 12 seconds, from 125°.

NOTE: Wave periods are a conservative property and remain constant when waves move from deep to shallow water, but speed, height, and steepness change.

Table 2-2. Shallow water wave directions and relative height conditions versus deep water period and direction (see Figure 2-2 for location of the points).

FORMAT: Shallow Water Direction
Wave Height Ratio: (Shallow Water/Deep Water)

MALAGA POINT 1 (Fleet Anchorage): 78 ft depth

Period (sec)	6	8	10	12	14	16
Deep Water Direction	Shallow Water Direction and Height Ratio					
090°	100°	100°	105°	110°	115°	120°
	.5	.4	.7	.7	.4	.4
120°	120°	120°	125°	125°	130°	135°
	1.0	.9	.8	.9	.8	1.0
150°	150°	145°	140°	145°	145°	145°
	1.0	1.0	1.0	.9	.8	.8
180°	180°	175°	170°	165°	160°	155°
	1.0	.8	.9	.9	.9	1.0
210°	200°	190°	180°	180°	175°	170°
	1.0	.8	.9	.6	.6	.6
240°	200°	190°	185°	185°	180°	175°
	1.0	.9	.9	.5	.4	.4

MALAGA POINT 2 (Harbor Entrance): 36 ft depth

Period (sec)	6	8	10	12	14	16
Deep Water Direction	Shallow Water Direction and Height Ratio					
090°	115°	100°	105°	110°	115°	120°
	.4	.4	.6	.5	.5	.5
120°	125°	125°	145°	135°	135°	135°
	.7	.7	.6	.5	.5	.8
150°	155°	145°	145°	150°	150°	145°
	.7	.7	.8	.5	.5	.7
180°	170°	165°	155°	155°	160°	145°
	.6	.7	.8	.7	.6	.8
210°	180°	170°	165°	165°	165°	155°
	.4	.3	.4	.6	.7	.6
240°	185°	180°	170°	165°	160°	155°
	.3	.3	.3	.3	.3	.3

The local wind generated wave conditions for the anchorage area identified as point 1 are given in Table 2-3. All heights refer to the significant wave height (average of the highest 1/3 waves). Enter the local wind speed and direction in this table to obtain the minimum duration in hours required to develop the indicated fetch limited sea height and period. The time to reach fetch limited height is based on an initial flat ocean. When starting from a pre-existing wave height, the time to fetch limited height will be shorter.

Table 2-3. Gulf of Malaga. Local wind waves for fetch limited conditions at point 1 (based on JONSWAP model).

Format: height (feet)/period (seconds)
time (hours) to reach fetch limited height

Direction and Fetch Length (n mi) \ Local Wind Speed (kt)	18	24	30	36	42
ENE 3 n mi	<2 ft	<2 ft	2/3 1	2/3 1	2-3/3 1
SW 5 n mi	<2 ft	2/3-4 1	2-3/3-4 1	3/3-4 1-2	3-4/3-4 1

Example:

To the southwest (225°) there is [illegible] a 5 n mi fetch. Given a southwest wind at 24 kt, the sea will have reached 2 feet with a period of 3-4 seconds in an 1 hour. Wind waves will not grow beyond this condition unless the wind speed increases or the direction changes to one over a longer fetch length. If the wind waves are superimposed on deep water swell, the combined height may change in response to changing swell conditions. Wind wave directions are assumed to be the same as the wind direction.

Climatological factors of shallow water waves, as described by percent occurrence, average duration, and period of maximum energy (period at which the most energy is focused for a given height), are given in Table 2-4. See Appendix A for discussion of wave spectrum and energy distribution. These data are provided by season for two ranges of heights: greater than 3.3 ft (1 m) and greater than 6.6 ft (2 m).

Table 2-4. Shallow water climatology as determined from deep water wave propagation. Percent occurrence, average duration or persistence, and wave period of maximum energy for wave height ranges of greater than 3.3 ft (1 m) and greater than 6.6 ft (2 m) by climatological season.

MALAGA POINT 1:	WINTER	SPRING	SUMMER	AUTUMN
>3.3 ft (1 m)	NOV-APR	MAY	JUN-SEP	OCT
Occurrence (%)	5	1	1	2
Average Duration (hr)	12	10	6	10
Period Max Energy (sec)	10	10	10	10
>6.6 ft (2 m)	NOV-APR	MAY	JUN-SEP	OCT
Occurrence (%)	2	0	0	1
Average Duration (hr)	8*	NA	NA	8
Period Max Energy (sec)	10	NA	NA	9

MALAGA POINT 2:	WINTER	SPRING	SUMMER	AUTUMN
>3.3 ft (1 m)	NOV-APR	MAY	JUN-SEP	OCT
Occurrence (%)	3	< 1	< 1	2
Average Duration (hr)	12	10	10	10
Period Max Energy (sec)	9	10	10	10
>6.6 ft (2 m)	NOV-APR	MAY	JUN-SEP	OCT
Occurrence (%)	1	0	0	1
Average Duration (hr)	9*	NA	NA	9
Period Max Energy (sec)	11	NA	NA	11

* Winter events of strong southeasterly gale force winds may last for 3-4 days.

SEASONAL SUMMARY OF HAZARDOUS WEATHER CONDITIONS

WINTER (November thru February):

* Worst conditions are easterly winds (Levante or Levanter) and are normally 20 kt but can reach 40 kt. Strong events last 3 or 4 days and high waves occur at anchorage and, to a lesser degree, in the harbor.
* Westerly winds (Vendaval and Poniente) can cause swell to enter the outer harbor while inner harbor not affected.

SPRING (March thru May):

* Early spring similar to winter - Levante still occurs but strong events less likely after April.
* Vendaval and Poniente events are less intense.
* Visibilities below 1 n mi due to fog/haze occur an average of three days/month.

SUMMER (June thru September):

* Sea breeze daily occurrence between 1100L and 1900L. Occasionally reaches 20-25 kt and will disrupt boating.

AUTUMN (October):

* Short transition season and winter weather returns by month's end.

NOTE: For more detailed information on hazardous weather conditions see previous Summary Table in this section and Hazardous Weather Summary in Section 3.

REFERENCES

Hydrographic Department, 1963: Mediterranean Pilot. Volume I. Published by the Hydrographic Department, under the authority of the Lords Commissioners of the Admiralty, London.

FICEURLANT, 1985: Port Directory. Fleet Intelligence Center Europe and Atlantic, Norfolk, VA.

3. GENERAL INFORMATION

This section is intended for Fleet meteorologists/oceanographers and staff planners. Paragraph 3.5 provides a general discussion of hazards and Table 3-5 provides a summary of vessel locations/situations, potential hazards, effects-precautionary/evasive actions, and advance indicators and other information about the potential hazards by season.

3.1 Geographic Location

The Port of Malaga, situated at 36°43'N 04°25'W on the south coast of Spain on the famed Costa del Sol (Coast of the Sun), is about 65 mi northeast of Gibraltar on the north shore of the Alboran Sea (Figure 3-1).

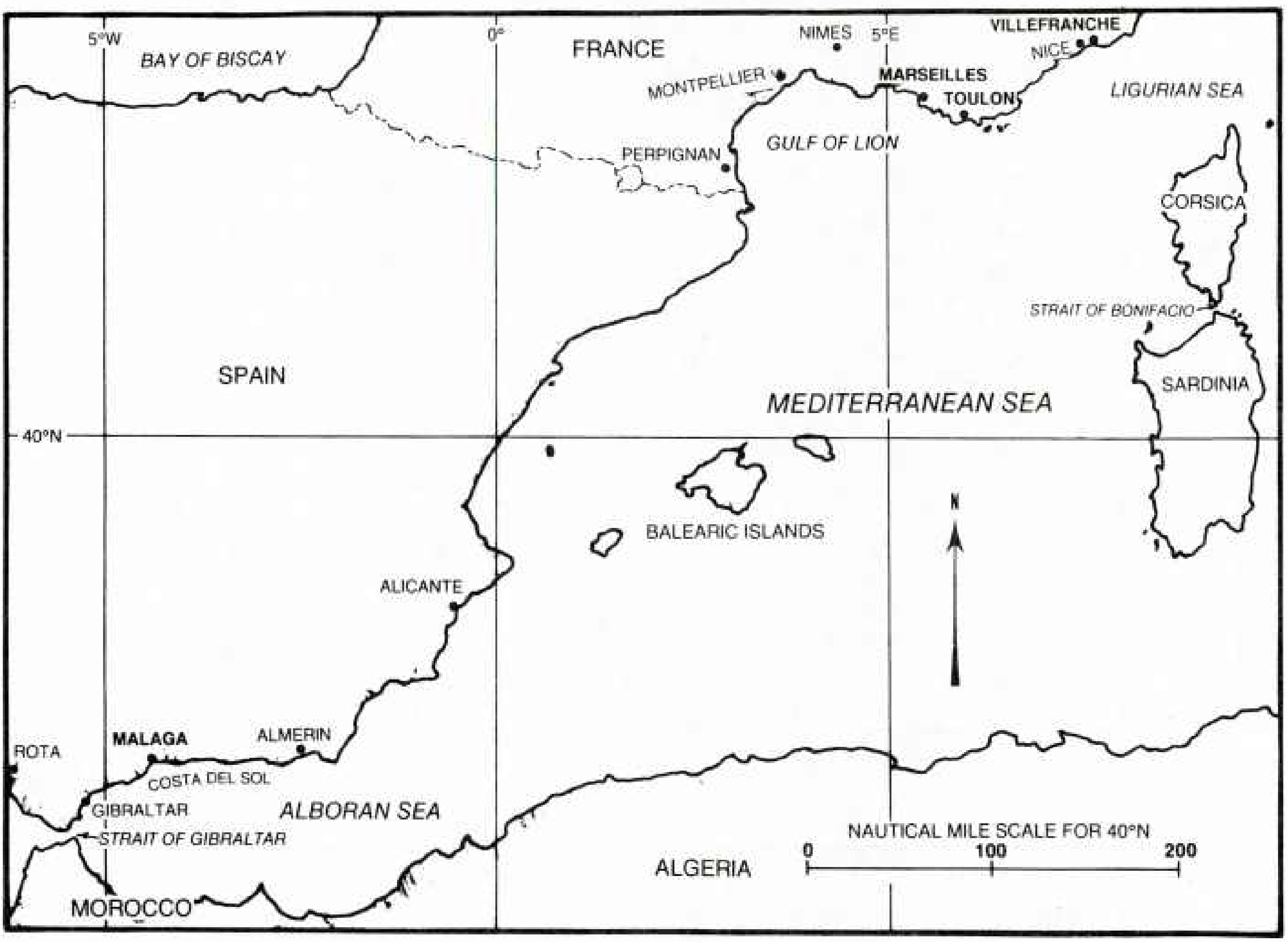

Figure 3-1. Western Mediterranean Sea.

The Port of Malaga is comprised of three inner harbors and an outer harbor, all of which are bounded by a series of moles and breakwaters. An anchorage used by U.S. Navy ships is located about 0.5 to 1 n mi east of the south end of the east breakwater (Dique del Este). See Figure 3-2. A prominent landmark near Malaga is the Castillo de Gibralfaro, a castle situated at an elevation of 463 ft (141 m) less than 1 mi north of the port.

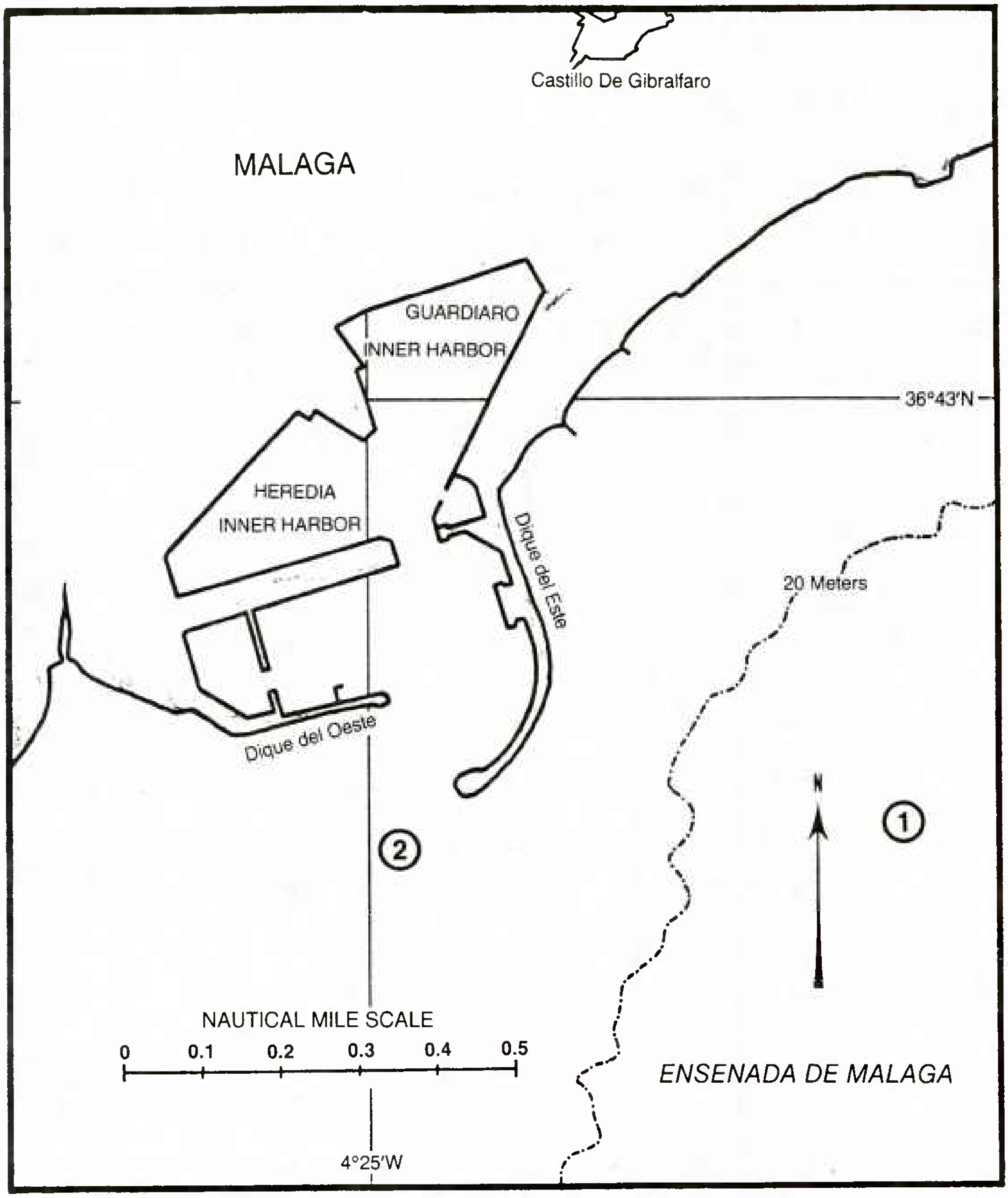

Figure 3-2. Port of Malaga.

3.2 Qualitative Evaluation of Harbor as a Haven

The Port of Malaga is bordered on the west and north by the coast of Spain, so wind and/or waves from west-southwest clockwise through east-northeast are not usually a problem to port operations other than the effect they may have on small boat operations. Winds and waves from other directions do cause difficulties at the Port.

East-southeasterly winds and waves are the biggest weather related problem at the Port. Strong east-southeasterly winds reaching force 8 (gale force, 34-40 kt) can be expected 2 or 3 times each winter, and be accompanied by swell waves to 13 ft.

Although the harbor is protected on the east by a long breakwater (Dique del Este), east to southeasterly waves cause major problems in the outer harbor. The west-moving waves refract clockwise around the end of the breakwater and pass through the harbor entrance. By the time the refraction is complete, the waves are moving northeasterly within the outer harbor. A large grain pier, to which large U.S. Navy ships sometimes moor, is impacted almost broadside by the wave motion. One example of the difficulties which can arise from the situation is that experienced by a U.S. Navy LPH moored to the pier in 1984. Strong southeasterly winds and accompanying waves struck Malaga. While the winds buffeted the upper, exposed portions of the vessel, it was being pushed against the pier in an opposing direction by the refracted waves. The result was a rocking motion of the ship which destroyed one fender and caused minor pier damage.

The southwest-facing harbor entrance also allows waves from the southwest to enter the harbor. Waves of sufficient size and period can create hazardous conditions at the grain pier. Small boating within the harbor may also be adversely affected.

The anchorage, located 0.5 to 1 n mi east of the breakwater, is exposed and vulnerable to the effects of winds and waves from east through southwest. The bottom of the anchorage is mostly mud with some sand and provides good holding, even in high wind/wave conditions (FICEURLANT, 1985). Vessels should normally use a single anchor (Hydrographic Department, 1963).

3.3 Currents and Tides

There is a persistent current with a south-westerly set near the entrance to the harbor, with a 2 kt velocity common. A 3 kt current has been observed in the vicinity of Dique del Oeste (west breakwater) (FICEURLANT, 1985). According to Hydrographic Department (1963), wind direction, sea state, and tidal conditions exert considerable influence on the rate and direction of the current. In one instance, on a calm day when a west-moving current was observed along the coast, a current flowing in the opposite direction was observed about 3 mi offshore.

The tidal range at the Port is about 2 ft (60 cm) but an easterly wind can increase water heights in the harbor.

3.4 Visibility

Visibility at the Port of Malaga is generally good, but local mariners say it reduces to less than 1 mi during early morning hours on about 8 days each spring and to near zero on 2 or 3 days.

3.5 Hazardous Conditions

The inner harbors of the Port of Malaga are well protected from the effects of most hazardous weather conditions, but the outer harbor and the anchorage are more exposed and vulnerable. A seasonal summary of the

various known environmental hazards that may be encountered in the Port of Malaga follows. Note that the period of the meteorological definitions of winter and spring vary from the oceanographic definitions as listed in Table 3-2.

A. Winter (November through February)

As detailed by Brody and Nestor (1980), the seasonal weather patterns in the Malaga area are controlled to a great degree by the movement of the semi-permanent Azores anticyclone. During winter, the upper-level westerlies and the extratropical storm track move southward, forcing the anticyclone to retreat. The result is a windy, wet, and mild winter weather regime at Malaga which is influenced by transient extratropical cyclones and anticyclones.

The worst environmental conditions in the Port are caused by winds with an easterly component. They are called Levante (the English name is Levanter), and can occur during any season in association with several different synoptic situations. Although most often in the 15-25 kt range, east-southeasterly winds of force 8 (gale force, 34-40 kt) with swell waves of 10 to 13 ft (3 to 4 m) can accompany an event at Malaga 2 or 3 times per winter. A strong event may last for 3 or 4 days. The winds and waves impact the anchorage directly, and as discussed in section 3.2 above, the waves can refract around the south end of the eastern protective breakwater. Levante winds in advance of an approaching cold front or low pressure system are often accompanied by low clouds and heavy rains. The winds may affect pilot boat operations since harbor pilots will not leave the harbor when winds reach force 6 (22-27 kt).

Westerly winds in the Alboran Sea are caused by two different sets of circumstances, and are known by two different names--Vendaval and Poniente. Vendaval winds are the southwesterly winds which precede cold fronts and commonly follow a Levante event. The Poniente is often associated with high pressure building eastward from the Atlantic following cold frontal passage. Vendaval winds

are usually the stronger of the two at Malaga, with gale force along the coast not uncommon. The Poniente winds, however, tend to be stronger 50 n mi or so offshore due to a lee trough which develops along the coast. Either wind can raise a southwesterly swell that passes through the southwest-facing harbor entrance at Malaga, making mooring in the outer harbor unsafe. Mooring in the inner harbor is minimally effected.

Warm Scirocco winds occasionally reach the Malaga area, but usually are not strong enough to cause significant problems at the Port. The Scirocco normally occurs in the warm sector of cyclones passing north of the area. A particularly strong event may raise a swell in the anchorage and reduce visibilities somewhat as Saharan dust is transported into the region. Low stratus and fog may accompany the Scirocco due to the relatively warm air absorbing water from the cool water surface.

A wind event, locally named "Terra," is the Spanish version of the infamous Mistral which occurs over the Gulf of Lion. The Terra winds which descend on the Port from the Spanish interior, may exceed 20 kt but generally cause no problems at the Port, except for small boat operations.

A sea breeze is evident at Malaga in all months except December and January. Onset usually occurs just before noon and lasts until about 1900L. A strong event may reach force 5 (17-21 kt). Since the direction of the sea breeze is south to southwest, and any southerly wind in excess of 12 kt causes waves in the harbor area to rise rapidly, the sea breeze can pose problems to small boat operations.

Winter temperatures are mild, with the mean temperature during January--the coldest month-- about 56°F (13°C). Wind chill is normally not a problem, but if a particularly cold air mass reaches the Port from the interior and is accompanied by Terra winds, the wind chill factor should be determined. Table 3-1 can be used to determine wind chill for various temperature and wind combinations.

Table 3-1. Wind Chill. The cooling power of the wind expressed as "Equivalent Chill Temperature" (adapted from Kotsch, 1983).

Wind Speed		Cooling Power of Wind expressed as "Equivalent Chill Temperature"								
Knots	MPH	Temperature (°F)								
Calm	Calm	40	35	30	25	20	15	10	5	0
		Equivalent Chill Temperature								
3-6	5	35	30	25	20	15	10	5	0	-5
7-10	10	30	20	15	10	5	0	-10	-15	-20
11-15	15	25	15	10	0	-5	-10	-20	-25	-30
16-19	20	20	10	5	0	-10	-15	-25	-30	-35
20-23	25	15	10	0	-5	-15	-20	-30	-35	-45
24-28	30	10	5	0	-10	-20	-25	-30	-40	-50
29-32	35	10	5	-5	-10	-20	-30	-35	-40	-50
33-36	40	10	0	-5	-15	-20	-30	-35	-45	-55

B. Spring (March through May)

The spring season in Malaga brings periods of stormy, winter-type weather which alternate with false starts of more settled, summer-type weather. Levante conditions continue to bring the worst environmental problems to the Port as the east to southeasterly swell impacts the anchorage and often refracts into the outer harbor. Strong events become less frequent after April.

Westerly winds, the Vendaval and the Poniente, are common through April. They generate swell which propagates through the Malaga harbor entrance and creates problems for ships moored in the outer harbor.

Springtime visibilities are the worst of the year, with the visibility expected to decrease below 1 mi on about 8 days. The worst visibility generally occurs during early morning. Near zero visibility can be expected during early morning hours on about 2 or 3 days of the season. Reduced visibility in dust from a Scirocco event also is possible.

A sea breeze will occur on warm days throughout the season, starting about noon and lasting until early evening. Force 4 or 5 (11-21 kt) is commonly reached. The direction of the sea breeze tends to "follow the sun" as hillsides are warmed by the changing direction of the sun, but are primarily south to southwest. Any southerly wind in excess of 12 kt causes waves in the harbor area to rise rapidly causing problems for small boat operations.

C. Summer (June through September)

There is little gradient wind at Malaga during summer, but what there is usually comes from the east or east-southeast (Levante). Temperatures are warm, and a daily sea breeze is the rule. Starting about 1100L, the wind may reach force 5 (17-21 kt) by mid afternoon, and last until about 1900L. The direction is generally south to southwesterly, but the breeze tends to change directions as the sun moves westward, following the sun as hillsides are warmed. A sea breeze in excess of 12 kt can quickly raise problem waves for small boats in the harbor area. The safe operating limit for small craft is about 3 ft (1 m), so boating may be affected (FICEURLANT, 1985).

Precipitation is at a yearly minimum during the summer, with July being the driest month. Haze is a common phenomena, but visibility is normally not restricted.

D. Autumn (October)

Autumn usually lasts for the single month of October, and is characterized by an abrupt change to winter-type weather (Brody and Nestor, 1980). The upper-level westerlies and the associated storm track move southward to their wintertime positions. Transient low pressure systems once again start to migrate through the region, causing alternating episodes of easterly Levante and westerly Vendaval and Poniente winds.

As discussed above for the winter season, the Levante winds bring the worst conditions to the Port of Malaga. Swell waves to 13 ft generated by Levante winds

reach the Port and impact the anchorage directly. In addition, they tend to refract clockwise around the south end of the east breakwater and create problems for ships moored in the outer harbor. The winds are commonly accompanied by low clouds and heavy rains.

Southwesterly swell generated by westerly Vendaval and Poniente winds pass through the harbor entrance and cause mooring problems in the outer harbor.

Any southerly wind of 12 kt or greater can quickly raise problem waves for small boats since their safe operation limit is 3 ft (1 m) (FICEURLANT, 1985). The sea breeze regime is evident throughout the month, and may be strong enough to raise 3 ft waves.

Malaga has an average of about 3 inches of precipitation during October, a monthly high for the year (tied with November).

3.6 Harbor Protection

As detailed below, some areas of the Port of Malaga are protected from the effects of wind and waves, while other areas are exposed and vulnerable.

3.6.1 Wind and Weather

The Sierra Nevada Range of the Baetic Mountains generally lie east-west north of Malaga, and serve as a barrier to most northerly wind flow at the Port. Wind flow can circumvent this barrier however, resulting in Malaga's prevailing northwesterly wind direction. The harbor at the Port is surrounded either by land or man-made piers, moles, and breakwaters, but they afford only minimal protection to vessels and small craft in the inner and outer harbors, and virtually none to ships outside the harbor entrance. Wind alone, however, does not seriously affect harbor operations to any significant degree. The greatest impact results from waves generated by the wind. Harbor pilots will not exit the harbor entrance when winds reach force 6 (22-27 kt) or greater.

3.6.2 Waves

On initial observation, the inner and outer harbors appear to be well protected from most wave activity, but a review of past events prove it to be a false assumption; the harbor is vulnerable. The worst scenario results when strong east to southeast (force 8, 34-40 kt) winds bring 10 to 13 ft (3 to 4 m) waves to the Port. The waves impact the anchorage directly. The holding qualities of the mud and sand bottom are good so ships at anchor can usually remain in the anchorage with little difficulty. The waves impact the east breakwater (Dique del Este) nearly broadside and refract clockwise around the south end of the breakwater and enter the outer harbor. Ships moored to the large grain pier located on the west side of the breakwater are simultaneously exposed to northeast moving swell waves and east-southeasterly winds. The result is a rocking motion at the pier endangering the ship, camels, and the pier.

Southwesterly swell waves generated by Vendaval and Poniente winds also pose a hazard to the same locations. The southwest facing harbor entrance allows the waves to enter the outer harbor directly, with some wave energy passing into the inner harbors through the 368 ft (112 m) wide entrance.

Small craft activity is affected by waves raised by southerly winds greater than 12 kt or northerly winds in excess of 20 kt. The winds can quickly raise a 3 ft (1 m) chop, which is the upper limit for small craft operation in the Port. Consequently, afternoon sea breezes which reach force 5 (17-21 kt) on warm summer days may cause curtailment of small boating.

Table 3-2 provides the shallow water wave conditions at the two designated points when deep water swell enters the harbor.

> Example: Use of Table 3-2.
>
> For a deep water wave condition of:
>
> 8 feet, 12 seconds, from 150°
>
> The approximate shallow water wave conditions are:
>
> Point 1: 7 feet, 12 seconds, from 145°
> Point 2: 4 feet, 12 seconds, from 150°

Table 3-2. Shallow water wave directions and relative height conditions versus deep water period and direction (see Figure 3-2 for location of the points).

FORMAT: Shallow Water Direction
Wave Height Ratio: (Shallow Water/Deep Water)

MALAGA POINT 1 (Fleet Anchorage): 78 ft depth

Period (sec)	6	8	10	12	14	16
Deep Water Direction	Shallow Water Direction and Height Ratio					
090°	100° .5	100° .4	105° .7	110° .7	115° .4	120° .4
120°	120° 1.0	120° .9	125° .8	125° .9	130° .8	135° 1.0
150°	150° 1.0	145° 1.0	140° 1.0	145° .9	145° .8	145° .8
180°	180° 1.0	175° .8	170° .9	165° .9	160° .9	155° 1.0
210°	200° 1.0	190° .8	180° .9	180° .6	175° .6	170° .6
240°	200° 1.0	190° .9	185° .9	185° .5	180° .4	175° .4

MALAGA POINT 2 (Harbor Entrance): 36 ft depth

Period (sec)	6	8	10	12	14	16
Deep Water Direction	Shallow Water Direction and Height Ratio					
090°	115° .4	100° .4	105° .6	110° .5	115° .5	120° .5
120°	125° .7	125° .7	145° .6	135° .5	135° .5	135° .8
150°	155° .7	145° .7	145° .8	150° .5	150° .5	145° .7
180°	170° .6	165° .7	155° .8	155° .7	160° .6	145° .8
210°	180° .4	170° .3	165° .4	165° .6	165° .7	155° .6
240°	185° .3	180° .3	170° .3	165° .3	160° .3	155° .3

Situation specific shallow water wave conditions resulting from deep water wave propagation are given in Table 3-2 while the seasonal climatology of wave conditions in the harbor resulting from the propagation of deep water waves into the harbor are given in Table 3-3. If the actual or forecast deep water wave conditions are known, the expected conditions at the two specified harbor areas can be determined from Table 3-2. The mean duration of the condition, based on the shallow water wave heights, can be obtained from Table 3-3.

<u>Example: Use of Tables 3-2 and 3-3</u>.

The forecast for <u>wave conditions</u> tomorrow (winter case) <u>outside the harbor are</u>:

8 feet, 14 seconds, from 120°

Expected <u>shallow water conditions</u> and <u>duration</u>:

	<u>Point 1</u>	<u>Point 2</u>
height	6-7 feet	4 feet
period	14 seconds	14 seconds
direction	from 130°	from 135°
duration	8-12 hours	12 hours

Interpretation of the information from Tables 3-2 and 3-3 provide guidance on the local wave conditions expected tomorrow at the various harbor points. The duration values are mean values for the specified height range and season. Knowledge of the <u>current synoptic pattern and forecast/expected duration should be used when available</u>. Note that the strongest winter events with southeasterly gale force winds can last for 3-4 days.

Possible applications to small boat operations are selection of the mother ships anchorage point and/or areas of small boat work. The condition duration information provides insight as to how long before a change can be expected. The local wave direction information can be of use in selecting anchorage configuration and related small boat operations, including tending activities.

Table 3-3. Shallow water climatology as determined from deep water wave propagation. Percent occurrence, average duration or persistence, and wave period of maximum energy for wave height ranges of greater than 3.3 ft (1 m) and greater than 6.6 ft (2 m) by climatological season.

MALAGA POINT 1:	WINTER	SPRING	SUMMER	AUTUMN
>3.3 ft (1 m)	NOV-APR	MAY	JUN-SEP	OCT
Occurrence (%)	5	1	1	2
Average Duration (hr)	12	10	6	10
Period Max Energy (sec)	10	10	10	10
>6.6 ft (2 m)	NOV-APR	MAY	JUN-SEP	OCT
Occurrence (%)	2	0	0	1
Average Duration (hr)	8*	NA	NA	8
Period Max Energy (sec)	10	NA	NA	9
MALAGA POINT 2:	**WINTER**	**SPRING**	**SUMMER**	**AUTUMN**
>3.3 ft (1 m)	NOV-APR	MAY	JUN-SEP	OCT
Occurrence (%)	3	< 1	< 1	2
Average Duration (hr)	12	10	10	10
Period Max Energy (sec)	9	10	10	10
>6.6 ft (2 m)	NOV-APR	MAY	JUN-SEP	OCT
Occurrence (%)	1	0	0	1
Average Duration (hr)	9*	NA	NA	9
Period Max Energy (sec)	11	NA	NA	11

* Winter events of strong southeasterly gale force winds may last 3-4 days.

Local wind wave conditions are provided in Table 3-4 for Malaga point 1. The fetch lengths are specifically for point 1. The time to reach the fetch limited height assumes an initial flat ocean. With a pre-existing wave height, the times are shorter.

Table 3-4. Gulf of Malaga. Local wind waves for fetch limited conditions at point 1 (based on JONSWAP model).

<u>Format:</u> height (feet)/period (seconds)
time (hours) to reach fetch limited height

Direction and\ Fetch \ Length \ (n mi)	Local Wind Speed (kt) 18	24	30	36	42
ENE 3 n mi	<2 ft	<2 ft	2/3 1	2/3 1	2-3/3 1
SW 5 n mi	<2 ft	2/3-4 1	2-3/3-4 1	3/3-4 1-2	3-4/3-4 1

<u>Example: Small boat wave forecasts</u> (based on the assumption that swell is not a limiting condition).

<u>Forecast for Tomorrow:</u>

<u>Time</u>	Wind <u>(Forecast)</u>	Waves <u>(Table 3-4)</u>
prior to 0700 LST	light and variable	< 1 ft
0700 to 1200	SW 8-10 kt	< 2 ft
1200 to 1800	SW 22-26 kt	building to 2 ft at 3-4 sec by 1300

<u>Interpretation</u>: Assuming that the limiting factor is waves greater than 3 feet, small boat operations would not be restricted on this day by wind waves alone. However, if there was also a southwest swell, conditions could be marginal.

Combined wave heights are computed by finding the square root of the sum of the squares of the wind wave and swell heights. For example, if the wind waves were 3 ft and the swell 8 ft the combined height would be about 8.5 ft.

$$\sqrt{3^2 + 8^2} = \sqrt{9 + 64} = \sqrt{73} \approx 8.5$$

Note that the increase in height is relatively small. Even if the two wave types were of equal height the combined heights are only 1.4 times the equal height. In cases where one or the other heights are twice that of the other, the combined height will only increase over the larger of the two by 1.12 times (10 ft swell and 5 ft wind wave combined results in 11.2 ft height).

3.6.3 Wave Data Uses and Considerations

Local wind waves build up quite rapidly and also decrease rapidly when winds subside. The period and therefore length of wind waves is generally short relative to the period and length of waves propagated into the harbor (see Appendix A). The shorter period and length result in wind waves being characterized by choppy conditions. When wind waves are superimposed on deep water waves propagated into shallow water, the waves can become quite complex and confused. Under such conditions, when more than one source of waves is influencing a location, tending or joint operations can be hazardous even if the individual wave train heights are not significantly high. Vessels of various lengths may respond with different motions to the diverse wave lengths present. The information on wave periods, provided in the previous tables, should be considered when forecasts are made for joint operations of various length vessels.

3.7 Protective and Mitigating Measures

3.7.1 Moving to New Anchorage

Although holding on the mud and sand bottom is good in high wind and wave conditions, a particularly strong Levante (southeasterly winds) event may dictate leaving the anchorage for a more protected port. Because of the configuration of the coastline, nearby options are non-existent. The closest port which regularly accommodates U.S. Navy ships is Rota, Spain which is located about 63 n mi northwest of Gibraltar. Wave action at Rota would be reduced to nil due to the offshore component of the wind, but Rota is uniquely affected by Levante winds. According to Brody and Nestor (1980), "the channeling effect through the Strait of Gibraltar combined with downslope flow appears to create super-gradient wind speeds." A Levante wind at Rota is typically southeasterly 18 to 24 kt with gusts to 28 to 34 kt and may last 8 days in the summer. If waves are the primary hazard to be avoided, Rota is a viable alternative to remaining at Malaga under Levante conditions. Winds and waves from other directions should not require a move.

3.7.2 Sortie/Remain in Port

As discussed in the preceding section, the only weather situation likely to force a decision about remaining in port or going to sea is a strong Levante event. Ships moored in the inner harbors should experience little difficulty so leaving the port should not be required. A vessel moored to the grain pier in the outer harbor should give serious consideration to a sortie if a strong Levante event is forecast. The likelihood of wave refraction around the south end of the east breakwater

and the possibility of damage to ship, camels, or pier due to the opposing forces of the waves and wind makes remaining at the pier a dangerous option.

3.7.3 Scheduling

The large-scale wind and wave events which adversely affect Port operations at Malaga are largely independent of diurnal variations which would make a certain time of day routinely better than another for the conduct of certain evolutions.

The sea breeze, which occurs during afternoons on warm days in all months except December and January, does have a specific cycle which should be considered when scheduling operations. If calm or light winds are required, operations should be scheduled for early morning or late evening.

3.8 Local Indicators of Hazardous Weather Conditions

The Port of Malaga is most vulnerable to two basic hazards: (1) wind and waves from the east to southeast, and (2) waves from the southwest. Other phenomena impact port operations to a lesser degree. In order to minimize potential damage or to avoid the hazard entirely, it is necessary to be aware of impending changes.

The following guidelines have been extracted from various sources and are intended to provide the insight necessary to enable the meteorologist to better understand various phenomena that affect the Port of Malaga.

3.8.1 Levante.

1. Seasonality.

Levante winds occur year round, but are most prevalent during summer.

2. <u>Causes</u>.

According to Brody and Nestor (1980), the Levante at Malaga may be caused by several synoptic situations:

(a) A typical summer Levante results when the Azores high pressure cell extends northeastward over Spain and southern France.

(b) A large high pressure cell over western Europe with low pressure over the western Mediterranean will produce a widespread Levante.

(c) A high pressure cell over the Balearic Islands will produce a localized Levante in the Alboran Channel and the Strait of Gibraltar.

(d) The basic cause of Levante winds is a northeast-southwest surface pressure gradient with highest pressure to the north and/or east.

(e) Cyclonic activity over the western Mediterranean Sea, northwest Africa, or over the North Atlantic west of northern Morocco will normally result in Levante conditions.

(f) During the October-April period, a large high pressure cell over western Europe will normally produce Levante conditions.

3. <u>Onset</u>.

(a) When a strong Levante is evident in the Strait of Gibraltar, southeasterly swell will reach Malaga in 24 hours. Conversely, a southeasterly swell in Malaga is indicative of Levante winds in the Strait.

(b) A rise in the water level in Malaga harbor will sometimes precede Levante winds.

(c) Forecasting sudden onset of Levante conditions during summer is aided by tracking old cold fronts moving southwestward along the coast of Spain. Tracking is facilitated by noting changes in humidity and wind direction from the normal sea breeze at coastal stations. Alicante (08539) is useful, but Almeria (08487/08488) is considered to be too far inland (Brody and Nestor, 1980).

(d) A gale force Levante can be expected in the Strait of Gibraltar when 300 mb winds over central

and south Spain veer from northwesterly to 040° (Brody and Nestor, 1980). A concurrent increase of lesser strength at Malaga is likely.

(e) Levante conditions are often preceded by a Mistral in the Gulf of Lion.

4. Intensity.

(a) Levante winds in the Strait of Gibraltar are usually in the 12-25 kt range; winds of 34+ kt (gale force) are rare (Brody and Nestor, 1980). See section 3.8.1.3(d) above. However, local mariners state winds of force 8 (34-40 kt) and waves to 10-13 ft (3-4 m) occur at Malaga.

(b) A 4 mb difference in surface pressure between Malaga and Rota (Malaga higher) will produce Levante winds of 30-35 kt in the Strait of Gibraltar (Brody and Nestor,1980).

5. Duration.

(a) Levante conditions may last 3-4 days if they reach force 8 (gale force, 34-40 kt). A force 8 event is reached 2-3 times per year at Malaga.

(b) Levante winds will cease when a depression passes the British Isles/France and the associated cold front starts to cross the Iberian Peninsula. Since westerlies replace easterlies while the front is still distant, the front need not progress as far south as Malaga for the Levante to end (Brody and Nestor, 1980).

6. General.

(a) With southeasterly Levante winds, a heavy swell rolls into the bay and breaks in depths of 5 fathoms southwest of the harbor (Hydrographic Department, 1963).

(b) In summer, Levante winds are accompanied by good weather and extensive haze. During the other seasons, however, Levante conditions bring low clouds, heavy rain and reduced visibility.

3.8.2 Vendaval.

The following is taken from Brody and Nestor (1980).

1. Seasonality.

Most common from November through April.

2. Cause.

Southwesterly Vendaval winds occur due to the pressure gradient pattern preceding cold fronts, and frequently follow a Levante event.

3. Intensity.

Force 8 (34-40 kt, gale force) is not uncommon.

4. General.

(a) Associated precipitation is usually of the non-convective type. The precipitation is often delayed 6-12 hr after Vendaval onset. The delay often misleads forecasters to believe that no precipitation is forthcoming.

3.8.3 Poniente.

1. Seasonality.

Most common during November - April period but may occur any time of the year.

2. Cause.

Poniente winds occur after a cold frontal passage when high pressure builds eastward from the Atlantic Ocean. Gale force winds in the Alboran Channel generally occur after the upper-level trough has moved east of the area.

3. Intensity.

The Sierra Nevada Mountains induce a lee trough along the south coast of Spain with the result that while it may be blowing hard from the southwest about 50 n mi offshore, the winds fall off towards the coast. Gale force southwesterlies often develop near the Algerian shore while light north-northwesterlies are observed near Malaga (Hydrographic Department, 1963).

4. Swell waves.

A southwesterly swell in the harbor may reach 6 ft (2 m) in height. A southwest swell in Malaga is indicative of Poniente winds in the Strait of Gibraltar.

5. General.

Associated weather is generally good, with mostly clear skies prevailing. A few cumulus clouds with occasional showers may be observed, with the showers most common over the water from 2200Z to 1000Z and over the land from 1500Z to 2000Z. Visibility is good outside of shower areas (Brody and Nestor, 1980).

3.8.4 Northerly "Terra" Winds

A surface pressure difference of 7 mb or more between Malaga and a point about 200 n mi north or northwest of Malaga (Malaga lower) will produce northerly winds of 20+ kt in the harbor (FICEURLANT, 1985). Adverse small craft operations may occur.

3.9 Summary of Problems, Actions, and Indicators

Table 3-5 is intended to provide an easy to use seasonal reference for meteorologists on ships using the Port of Malaga. Table 2-1 (section 2) summarizes Table 3-5 and is intended primarily for use by ship Captains.

Table 3-5. Potential problem situations at Port of Malaga - ALL SEASONS

VESSEL LOCATION/SITUATION	POTENTIAL HAZARD	EFFECT - PRECAUTIONARY/EVASIVE ACTIONS	ADVANCE INDICATORS AND OTHER INFORMATION ABOUT POTENTIAL HAZARD
1. Moored - inner harbor. Strongest in Winter & early Spring Most common in Summer Autumn	a. Levante winds - E to SE'ly winds which may attain force 8 (34-40 kt) and last 3-4 days.	a. Minimal effect in inner harbor. Depending on ships orientation, additional mooring lines may be required to prevent excessive vessel movement due to wind force. Minimize personnel exposure on weather decks in strong event.	a. There are many guidelines relating to the causes, onset, intensity, and duration of Levante conditions at Malaga. Refer to section 3.8.1 of the accompanying text for an extensive discussion.
Winter Spring Uncommon in Summer Autumn	b. SW'ly swell - Generated by SW'ly Vendaval winds or W to NW'ly Poniente winds which precede/follow cold frontal passages. Swell to 6 ft (2 m) can pass through outer and inner harbor entrances and minimally impact inner harbor operations. Most common November - April.	b. Swell which passes into inner harbor may cause movement of moored vessels. Additional mooring lines may be required to prevent excessive vessel movement.	b. SW'ly swell may be caused by SW'ly Vendaval winds which precede cold fronts, or W to NW'ly Poniente winds which follow cold frontal passage when high pressure builds eastward from the Atlantic ocean. Several guidelines relating to Vendaval and Poniente winds can be found in sections 3.8.2 and 3.8.3 of the accompanying text.
Winter Spring Uncommon in Summer Autumn	c. Vendaval winds - SW'ly winds which usually follow a Levante event and precede cold frontal passage. They may reach force 8 (34-40 kt) and impact inner Port operations. Most common November - April.	c. Minimal effect. Depending on ships orientation, additional mooring lines may be required to prevent excessive vessel movement. Minimize personnel exposure on weather decks.	c. Several guidelines relating to Vendaval winds can be found in section 3.8.2 of the accompanying text.
2. Moored - outer harbor. Strongest in Winter & early Spring Most common in Summer Autumn	a. Levante winds/waves - E to SE'ly winds which may attain force 8 (34-40 kt), last 3-4 days, and create the worst weather related conditions at the Port. Waves of 10-13 ft (3-4 m) tend to refract around the S end of the E breakwater and impact the grain pier (where large U.S. Navy ships moor) on the E side of the outer harbor.	a. Refracted waves strike the grain pier nearly broadside, and in a direction opposed to that of the wind. The combined forces of wind and waves cause excessive vessel rolling at pierside, hazarding the vessel and the pier/camels. Evasion at sea is recommended. Minimize personnel exposure on weather decks.	a. There are many guidelines relating to the causes, onset, intensity, and duration of Levante conditions at Malaga. Refer to section 3.8.1 of the accompanying text for an extensive discussion.
Winter Spring Uncommon in Summer Autumn	b. SW'ly swell - Generated by SW'ly Vendaval winds or W to NW'ly Poniente winds which precede/follow cold frontal passages over the Alboran Sea. Swell to 6 ft (2 m) can pass through the entrance to the outer harbor and impact the grain pier (where large U.S. Navy ships moor) on the W side of the E breakwater. Most common November - April.	b. The swell can reach the grain pier on the east side of the harbor, with the potential to cause excessive motion of ships moored alongside and consequent damage to vessels, camels, and pier. If wave height indicates significant movement, vessels are advised to leave the outer harbor and anchor, or put to sea as conditions warrant.	b. SW'ly swell may be caused by SW'ly Vendaval winds which precede cold fronts, or W to NW'ly Poniente winds which follow cold frontal passage when high pressure builds eastward from the Atlantic ocean. Several guidelines relating to Vendaval and Poniente winds can be found in sections 3.8.2 and 3.8.3 of the accompanying text.
Winter Spring Uncommon in Summer Autumn	c. Vendaval winds - SW'ly winds which usually follow a Levante event and precede cold frontal passage. They may reach force 8 (34-40 kt) and impact outer Port operations. Most common November - April.	c. Minimal effect. Additional mooring lines may be required to prevent excessive vessel movement. Minimize personnel exposure on weather decks.	c. Several guidelines relating to Vendaval winds can be found in section 3.8.2 of the accompanying text.

Table 3-5. (Continued)

VESSEL LOCATION/SITUATION	POTENTIAL HAZARD	EFFECT - PRECAUTIONARY/EVASIVE ACTIONS	ADVANCE INDICATORS AND OTHER INFORMATION ABOUT POTENTIAL HAZARD
3. Anchored. Strongest in Winter & early Spring Most common in Summer Autumn	a. Levante winds/waves - E to SE'ly winds which may attain force 8 (34-40 kt), last 3-4 days, and create the worst weather related conditions at the Port. Waves of 10-13 ft (3-4 m) may impact the anchorage.	a. Holding is good on a bottom of sand and mud (mostly mud), even in high winds and seas (U.S. Navy, 1985). Vessels are recommended to lie at a single anchor (Hydrographic Department, 1963), but high winds and seas may require the deployment of an additional anchor. Evasion at sea or moving to a different anchorage is not usually required, but a particularly strong event may dictate leaving the anchorage. Nearby anchorages which would afford better protection from Levante winds and seas are non-existent due to coastline configuration. The coast of Spain west of Gibraltar would afford better protection from waves, but some areas such as Rota experience increased wind speeds due to a combination of factors. It is also likely that conditions in the Strait of Gibraltar would be significantly higher than those at Malaga due to funneling. Minimize personnel exposure on weatherdecks.	a. There are many guidelines relating to the causes, onset, intensity, and duration of Levante conditions at Malaga. Refer to section 3.8.1 of the accompanying text for an extensive discussion.
Winter Spring Uncommon in Summer Autumn	b. SW'ly swell - Generated by SW'ly Vendaval winds or W to NW'ly Poniente winds which precede/follow cold frontal passages. Swell of 6 ft (2 m) or higher may reach anchorage. Most common November - April.	b. Good holding afforded by mud and sand bottom (mostly mud) should be adequate to allow ships to remain in the anchorage. A second anchor may be required if high swell is expected.	b. SW'ly swell may be caused by SW'ly Vendaval winds which precede cold fronts, or W to NW'ly Poniente winds which follow cold frontal passage when high pressure builds eastward from the Atlantic ocean. Several guidelines relating to Vendaval and Poniente winds can be found in sections 3.8.2 and 3.8.3 of the accompanying text.
Winter Spring Uncommon in Summer Autumn	c. Vendaval winds - SW'ly winds which usually follow a Levante event and precede cold frontal passage. Velocities of force 8 (34-40 kt) may be attained. Most common November - April.	c. Winds alone should pose only minimal problems. Minimize personnel exposure on weather decks.	c. Several guidelines relating to Vendaval winds can be found in section 3.8.2 of the accompanying text.
4. Arriving/departing. Strongest in Winter & early Spring Most common in Summer Autumn	a. Levante winds/waves - E to SE'ly winds which may attain force 8 (34-40 kt), last 3-4 days, and create the worst weather related conditions at the Port. Waves of 10-13 ft (3-4 m) may impact the anchorage and refract into the outer harbor.	a. A strong event may preclude inbound vessels from entering the Port of Malaga. As discussed in paragraphs 2.a and 3.a above, remaining in the Port may not be prudent. Outbound vessels are advised to accelerate their departure to avoid any forecast strong Levante event. Inbound vessels should delay arrival until after strong Levante conditions subside. Pilot boats will not leave the harbor if winds exceed force 5 (17-21 kt).	a. There are many guidelines relating to the causes, onset, intensity, and duration of Levante conditions at Malaga. Refer to section 3.8.1 of the accompanying text for an extensive discussion.
Winter Spring Uncommon in Summer Autumn	b. Vendaval winds/waves - SW'ly winds which precede cold frontal passage. May reach force 8 (34-40 kt) and generate SW'ly waves of 6 ft (2 m) or higher in Port area. Most common November - April.	b. Depending on forecast conditions, inbound/outbound vessels should alter plans as necessary to avoid the highest Vendaval winds and waves. Winds of 20 kt or less should pose only minimal problems in the Port. Pilot boats will not leave the harbor if winds exceed force 5 (17-21 kt).	b. Several guidelines relating to Vendaval winds can be found in section 3.8.2 of the accompanying text.
Winter Spring Uncommon in Summer Autumn	c. Poniente winds/waves - W to NW'ly winds which follow cold frontal passage. Winds near the coast are generally light due to a lee trough, but strong SW'ly winds are usually observed about 50 n mi offshore. Wind generates SW'ly waves which reaches the Port as 6 ft (2 m) swell. Most common November - April.	c. Due to the lee trough effect, vessels should be able to conduct normal operations at the Port, but swell wave motion may impact some evolutions in the harbors and anchorage. Outbound vessels should anticipate encountering increased wind and waves when outside the protection afforded by the lee trough.	c. Several guidelines relating to Poniente winds can be found in section 3.8.3 of the accompanying text.

VESSEL LOCATION/SITUATION	POTENTIAL HAZARD	EFFECT - PRECAUTIONARY/EVASIVE ACTIONS	ADVANCE INDICATORS AND OTHER INFORMATION ABOUT POTENTIAL HAZARD
5. Small boats. Strongest in Winter & early Spring Most common in Summer Autumn	a. Levante winds/waves - E to SE'ly winds which may attain force 8 (34-40 kt), last 3-4 days, and create the worst weather related conditions at the Port. Waves of 10-13 ft (3-4 m) may impact the anchorage and refract into the outer harbor.	a. The upper limits of wave heights for safe boat operation in the Port is 3 ft (1 m). Small boats will not leave the outer harbor if the wind exceeds force 5 (17-21 kt). Boating to/from the anchorage will likely be curtailed until the winds/waves subside.	a. There are many guidelines relating to the causes, onset, intensity, and duration of Levante conditions at Malaga. Refer to section 3.8.1 of the accompanying text for an extensive discussion.
Winter Spring Uncommon in Summer Autumn	b. Vendaval winds/waves - SW'ly winds which precede cold frontal passage. May reach force 8 (34-40 kt) and generate SW'ly waves of 6 ft (2 m) or higher in Port area. Most common November - April.	b. The upper limits of wave heights for safe boat operation in the Port is 3 ft (1 m). Small boats will not leave the outer harbor if the wind exceeds force 5 (17-21 kt). Boating to/from the anchorage will likely be curtailed until the winds/waves subside.	b. Several guidelines relating to Vendaval winds can be found in section 3.8.2 of the accompanying text.
Winter Spring Uncommon in Summer Autumn	c. Poniente winds/waves - W to NW'ly winds which follow cold frontal passage. Winds near the coast are generally light due to a lee trough, but strong SW'ly winds are usually observed about 50 n mi offshore. Wind generates SW'ly waves which reaches the Port as 6 ft (2 m) swell. Most common November - April.	c. The upper limits of wave heights for safe boat operation in the Port is 3 ft (1 m). Small boats will not leave the outer harbor if the wind exceeds force 5 (17-21 kt). Boating to/from the anchorage will likely be curtailed until the winds/waves subside.	c. Several guidelines relating to Poniente winds can be found in section 3.8.3 of the accompanying text.
Winter Early Spring Late Autumn	d. N'ly "Terra" winds/waves - Winds of 20+ kt can be caused by high pressure N of Malaga and steep pressure gradient over the area. Although fetch is short, waves that hamper small boat operation in the harbor can result.	d. The upper limits of wave heights for safe boat operation in the Port is 3 ft (1 m). Small boats will not leave the outer harbor if the wind exceeds force 5 (17-21 kt). Boating to/from the anchorage will likely be curtailed until the winds/waves subside. Be aware of wind chill factor.	d. A 7 mb pressure difference between Malaga and a point about 200 n mi inland N, or NW of Malaga (Malaga lower) will result in N'ly winds of 20+ kt in the harbor.
Winter Spring Strongest in Summer Autumn	e. Sea breeze - Afternoon sea breeze can reach force 5 (17-21 kt). Usually starts about 1100L and lasts until 1900L. Not usually observed in December and January. Direction is generally S to SW but direction "follows the sun" as hillsides are warmed.	e. A sea breeze in excess of 12 kt can quickly raise problem waves for small boats in the harbor area. The safe operating limit for small craft is about 3 ft (1 m).	e. The sea breeze occurs at Malaga during all months except December and January. Strongest and occurring daily during the summer months, it may be expected in other seasons whenever a steep pressure gradient is not influencing the wind regime over the area.

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PORT VISIT INFORMATION

JUNE 1986. NEPRF meteorologists R. Fett and R. Picard met with the Chief Pilot to obtain much of the information included in this port evaluation.

APPENDIX A

General Purpose Oceanographic Information

This section provides general information on wave forecasting and wave climatology as used in this study. The forecasting material is not harbor specific. The material in paragraphs A.1 and A.2 was extracted from H.O. Pub. No. 603, Practical Methods for Observing and Forecasting Ocean Waves (Pierson, Neumann, and James, 1955). The information on fully arisen wave conditions (A.3) and wave conditions within the fetch region (A.4) is based on the JONSWAP model. This model was developed from measurements of wind wave growth over the North Sea in 1973. The JONSWAP model is considered more appropriate for an enclosed sea where residual wave activity is minimal and the onset and end of locally forced wind events occur rapidly (Thornton, 1986), and where waves are fetch limited and growing (Hasselmann, et al., 1976). Enclosed sea, rapid onset/subsiding local winds, and fetch limited waves are more representative of the Mediterranean waves and winds than the conditions of the North Atlantic from which data was used for the Pierson and Moskowitz (P-M) Spectra (Neumann and Pierson 1966). The P-M model refined the original spectra of H.O. 603, which over developed wave heights.

The primary difference in the results of the JONSWAP and P-M models is that it takes the JONSWAP model longer to reach a given height or fully developed seas. In part this reflects the different starting wave conditions. Because the propagation of waves from surrounding areas into semi-enclosed seas, bays, harbors, etc. is limited, there is little residual wave action following periods of locally light/calm winds and the sea surface is nearly flat. A local wind developed wave growth is therefore slower than wave growth in the open ocean where some residual wave action is generally always

present. This slower wave development is a built in bias in the formulation of the JONSWAP model which is based on data collected in an enclosed sea.

A.1 Definitions

Waves that are being generated by local winds are called "SEA". Waves that have traveled out of the generating area are known as "SWELL". Seas are chaotic in period, height and direction while swell approaches a simple sine wave pattern as its distance from the generating area increases. An in-between state exists for a few hundred miles outside the generating area and is a condition that reflects parts of both of the above definitions. In the Mediterranean area, because its fetches and open sea expanses are limited, SEA or IN- BETWEEN conditions will prevail. The "SIGNIFICANT WAVE HEIGHT" is defined as the average value of the heights of the one-third highest waves. PERIOD and WAVE LENGTH refer to the time between passage of, and distances between, two successive crests on the sea surface. The FREQUENCY is the reciprocal of the period ($f = 1/T$) therefore as the period increases the frequency decreases. Waves result from the transfer of energy from the wind to the sea surface. The area over which the wind blows is known as the FETCH, and the length of time that the wind has blown is the DURATION. The characteristics of waves (height, length, and period) depend on the duration, fetch, and velocity of the wind. There is a continuous generation of small short waves from the time the wind starts until it stops. With continual transfer of energy from the wind to the sea surface the waves grow with the older waves leading the growth and spreading the energy over a greater range of frequencies. Throughout the growth cycle a SPECTRUM of ocean waves is being developed.

A.2 Wave Spectrum

Wave characteristics are best described by means of their range of frequencies and directions or their spectrum and the shape of the spectrum. If the spectrum of the waves covers a wide range of frequencies and directions (known as short-crested conditions), SEA conditions prevail. If the spectrum covers a narrow range of frequencies and directions (long crested conditions), SWELL conditions prevail. The wave spectrum depends on the duration of the wind, length of the fetch, and on the wind velocity. At a given wind speed and a given state of wave development, each spectrum has a band of frequencies where most of the total energy is concentrated. As the wind speed increases the range of significant frequencies extends more and more toward lower frequencies (longer periods). The frequency of maximum energy is given in equation 1.1 where v is the wind speed in knots.

$$f_{max} = \frac{2.476}{v} \qquad (1.1)$$

The wave energy, being a function of height squared, increases rapidly as the wind speed increases and the maximum energy band shifts to lower frequencies. This results in the new developing smaller waves (higher frequencies) becoming less significant in the energy spectrum as well as to the observer. As larger waves develop an observer will pay less and less attention to the small waves. At the low frequency (high period) end the energy drops off rapidly, the longest waves are relatively low and extremely flat, and therefore also masked by the high energy frequencies. The result is that 5% of the upper frequencies and 3% of the lower frequencies can be cut-off and only the remaining

frequencies are considered as the <u>"significant part of the wave spectrum"</u>. The resulting range of significant frequencies or periods are used in defining a fully arisen sea. For a fully arisen sea the approximate average period for a given wind speed can be determined from equation (1.2).

$$\bar{T} = 0.285v \tag{1.2}$$

Where v is wind speed in knots and T is period in seconds. The approximate average wave length in a fully arisen sea is given by equation (1.3).

$$\bar{L} = 3.41\ \bar{T}^2 \tag{1.3}$$

Where $\bar{L}$ is average wave length in feet and $\bar{T}$ is average period in seconds.

The approximate average wave length of a fully arisen sea can also be expressed as:

$$\bar{L} = .67"L" \tag{1.4}$$

where "L" = $5.12T^2$, the wave length for the classic sine wave.

A.3 Fully Arisen Sea Conditions

For each wind speed there are minimum fetch (n mi) and duration (hr) values required for a fully arisen sea to exist. Table A-1 lists minimum fetch and duration values for selected wind speeds, values of significant wave (average of the highest 1/3 waves) period and height, and wave length of the average wave during developing and fully arisen seas. The minimum duration time assumes a start from a flat sea. When pre-existing

lower waves exist the time to fetch limited height will be shorter. Therefore the table duration time represents the maximum duration required.

Table A-1. Fully Arisen Deep Water Sea Conditions Based on the JONSWAP Model.

Wind Speed (kt)	Minimum Fetch/Duration (n mi) (hrs)	Sig Wave (H1/3) Period/Height (sec) (ft)	Wave Length (ft)[1,2] Developing/Fully /Arisen L X (.5) /L X (.67)
10	28 / 4	4 / 2	41 / 55
15	55 / 6	6 / 4	92 / 123
20	110 / 8	8 / 8	164 / 220
25	160 / 11	9 / 12	208 / 278
30	210 / 13	11 / 16	310 / 415
35	310 / 15	13 / 22	433 / 580
40	410 / 17	15 / 30	576 / 772

NOTES:

[1] Depths throughout fetch and travel zone must be greater than 1/2 the wave length, otherwise shoaling and refraction take place and the deep water characteristics of waves are modified.

[2] For the classic sine wave the wave length (L) equals 5.12 times the period (T) squared ($L = 5.12T^2$). As waves develop and mature to fully developed waves and then propagate out of the fetch area as swell their wave lengths approach the classic sine wave length. Therefore the wave lengths of developing waves are less than those of fully developed waves which in turn are less than the length of the resulting swell. The factor of .5 (developing) and .67 (fully developed) reflect this relationship.

A.4 Wave Conditions Within The Fetch Region

Waves produced by local winds are referred to as SEA. In harbors the local sea or wind waves may create hazardous conditions for certain operations. Generally within harbors the fetch lengths will be short and therefore the growth of local wind waves will be fetch limited. This implies that there are locally determined upper limits of wave height and period for each wind velocity. Significant changes in speed or direction will result in generation of a new wave group with a new set of height and period limits. Once a fetch limited sea reaches its upper limits no further growth will occur unless the wind speed increases.

Table A-2 provides upper limits of period and height for given wind speeds over some selected fetch lengths. The duration in hours required to reach these upper limits (assuming a start from calm and flat sea conditions) is also provided for each combination of fetch length and wind speed. Some possible uses of Table A-2 information are:

1) If the only waves in the area are locally generated wind waves, the Table can be used to forecast the upper limit of sea conditions for combinations of given wind speeds and fetch length.

2) If deep water swell is influencing the local area in addition to locally generated wind waves, then the Table can be used to determine the wind waves that will combine with the swell. Shallow water swell conditions are influenced by local bathymetry (refraction and shoaling) and will be addressed in each specific harbor study.

3) Given a wind speed over a known fetch length the maximum significant wave conditions and time needed to reach this condition can be determined.

Table A-2. Fetch Limited Wind Wave Conditions and Time Required to Reach These Limits (Based on JONSWAP Model). Enter the table with wind speed and fetch length to determine the significant wave height and period, and time duration needed for wind waves to reach these limiting factors. All of the fetch/speed combinations are fetch limited except the 100 n mi fetch and 18 kt speed.

Format: height (feet)/period (seconds)
duration required (hours)

Fetch Length (n mi) \ Wind Speed (kt)	18	24	30	36	42
10	2/3-4 1-2	3/3-4 2	3-4/4 2	4/4-5 1-2	5/5 1-2
20	3/4-5 2-3	4/4-5 3	5/5 3	6/5-6 3-4	7/5-6 3
30	3-4/5 3	5/5-6 4	6/6 3-4	7/6 3-4	8/6-7 3
40	4-5/5-6 4-5	5/6 4	6-7/6-7 4	8/7 4	9-10/7-8 3-4
100	5/6-7[1] 5-6	9/8 8	11/9 7	13/9 7	15-16/9-10 7

[1] 18 kt winds are not fetch limited over a 100 n mi fetch.

An example of expected wave conditions based on Table A-2 follows:

WIND FORECAST OR CONDITION

An offshore wind of about 24 kt with a fetch limit of 20 n mi (ship is 20 n mi from the coast) is forecast or has been occurring.

SEA FORECAST OR CONDITION

From Table A-2: If the wind condition is forecast to last, or has been occurring, for at least 3 hours:

Expect sea conditions of 4 feet at 4-5 second period to develop or exist. If the condition lasts less than 3 hours the seas will be lower. If the condition lasts beyond 3 hours the sea will not grow beyond that developed at the end of about 3 hours unless there is an increase in wind speed or a change in the direction that results in a longer fetch.

A.5 Wave Climatology

The wave climatology used in these harbor studies is based on 11 years of Mediterranean SOWM output. The MED-SOWM is discussed in Volume II of the U.S. Naval Oceanography Command Numerical Environmental Products Manual (1986). A deep water MED-SOWM grid point was selected as representative of the deep water wave conditions outside each harbor. The deep water waves were then propagated into the shallow water areas. Using linear wave theory and wave refraction computations the shallow water climatology was derived from the modified deep water wave conditions. This climatology does not include the local wind generated seas. This omission, by design, is accounted for by removing all wave data for periods less than 6 seconds in the climatology. These shorter period waves are typically dominated by locally generated wind waves.

A.6 Propagation of Deep Water Swell Into Shallow Water Areas

When deep water swell moves into shallow water the wave patterns are modified, i.e., the wave heights and directions typically change, but the wave period remains constant. Several changes may take place including shoaling as the wave feels the ocean bottom, refraction as the wave crest adjusts to the bathymetry pattern, changing so that the crest becomes more parallel to the bathymetry contours, friction with the bottom sediments, interaction with currents, and adjustments caused by water temperature gradients. In this work, only shoaling and refraction effects are considered. Consideration of the other factors are beyond the resources available for this study and, furthermore, they are considered less significant in the harbors of this study than the refraction and shoaling factors.

To determine the conditions of the deep water waves in the shallow water areas the deep water

conditions were first obtained from the Navy's operational MED-SOWM wave model. The bathymetry for the harbor/area of interest was extracted from available charts and digitized for computer use. Figure A-1 is a sample plot of bathymetry as used in this project. A ray path refraction/shoaling program was run for selected combinations of deep water wave direction and period. The selection was based on the near deep water wave climatology and harbor exposure. Each study area requires a number of ray path computations. Typically there are 3 or 4 directions (at 30° increments) and 5 or 6 periods (at 2 second intervals) of concern for each area of study. This results in 15 to 24 plots per area/harbor. To reduce this to a manageable format for quick reference, specific locations within each study area were selected and the information was summarized and is presented in the specific harbor studies in tabular form.

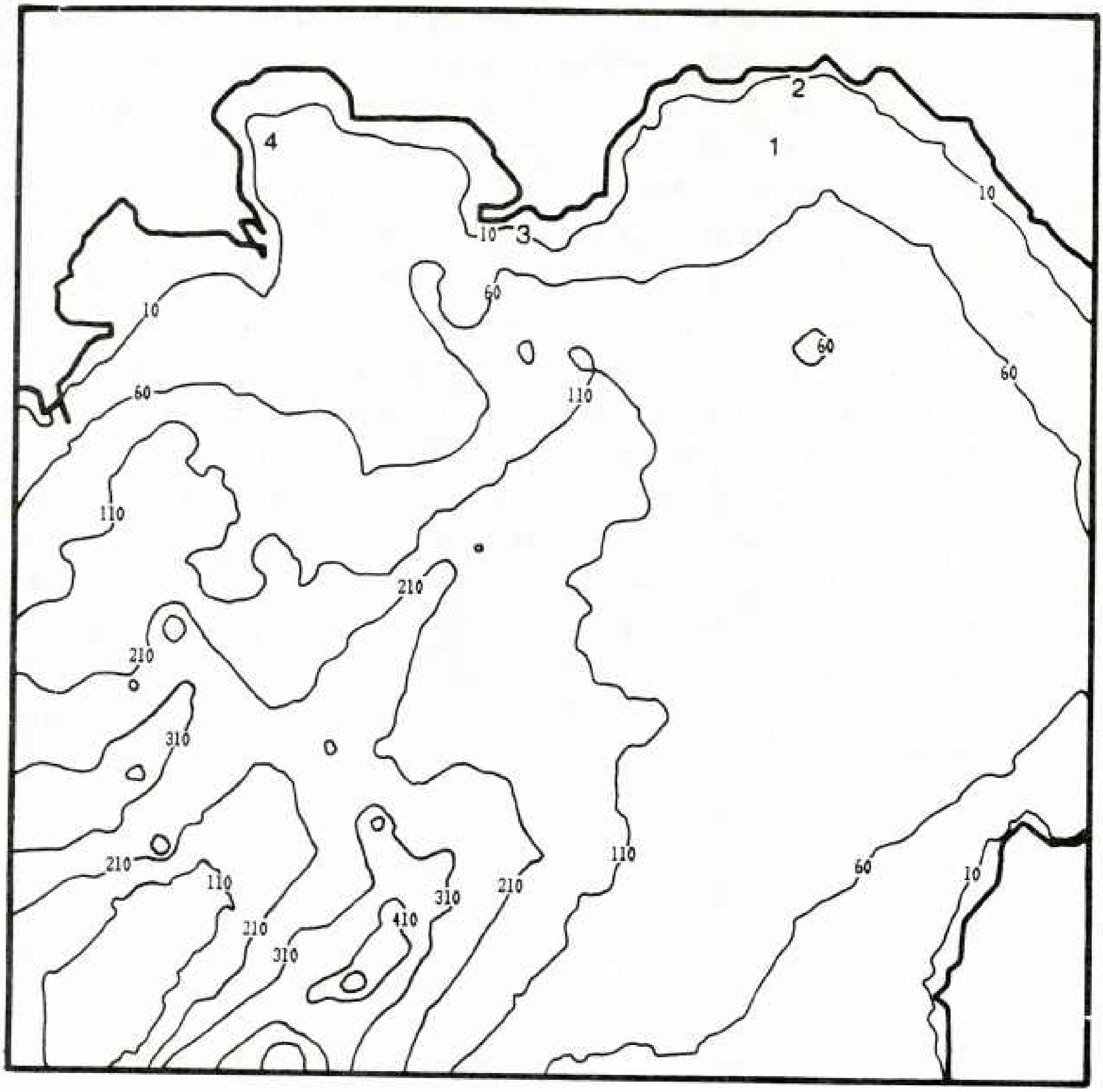

Figure A-1. Example plot of bathymetry (Naples harbor) as used in this project. For plotting purposes only, contours are at 50 fathom intervals from an initial 10 fathoms to 110 fathoms, and at 100 fathom intervals thereafter. The larger size numbers identify specific anchorage areas addressed in the harbor study.

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